Lithium ION Battery Technology

Is Lithium Ion Battery Technology Right For You?

What has changed in 2021?

Presented By:

Marlene McCartha, AC & DC Power Technologies

Battery Technology- *Applications*

Applications Considered Today: WHY?
Applications prevalent in new construction for:
▪ **Data Centers,**
▪ **Manufacturing Operations,**
▪ **Institutional Buildings,**
▪ **Process Control,**
▪ **Transit Systems**

We will **not** consider consumer electronics (cell phones, hand tools, cameras, computers) or motive applications (forklifts, electric vehicles, etc.) for this presentation.






Lithium ION Battery Technology- *Applications*

Applications Considered Today: WHY?

Applications prevalent in new construction for:

What these applications have in common:

1. They all use primarily taper current charging systems,
2. They are all emergency standby applications,
3. They all are primarily float charging applications,
4. These systems are rarely cycled to a significant depth of discharge (with the exception of PV systems).

NMC
LFP
LTO
NCA

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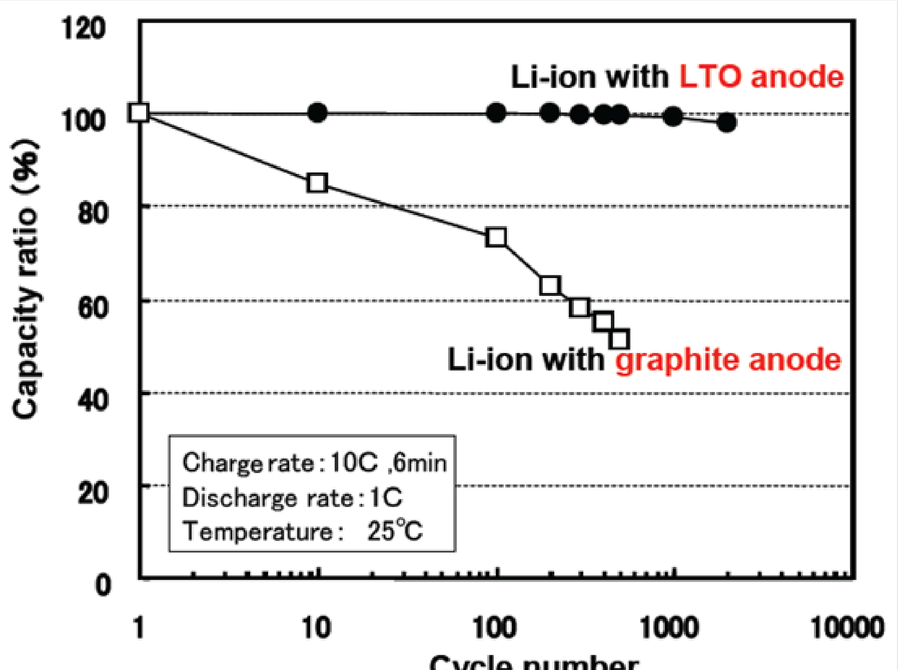
Battery Failures

Modes of Failure	Lead Acid	Nickel Cadmium	Lithium
Natural Aging	Open Circuit (Sudden Death)	Gradual reduction of capacity	Gradual reduction of capacity (SEI interface growth Lithium Plating, Intercalation)
Premature Failure	Typically Open Circuit	Gradual loss of capacity	Loss of communication
Manufacturing Defects	Rare	Rare	Rare

Lithium ION Battery Technology- *End of Life*

Aging Mechanisms:	Resulting Symptom
Intercalation **(Natural)**	▪ Parasitic chemical reactions that prevent the lithium ions from populating the interstices of the active materials. Conductivity of the battery is gradually reduced as this occurs.
Repetitive Cycling **(Natural)**	▪ **Very gradual decline of BOL capacity.** 

Lithium ION Battery Technology- *End of Life*

Premature Aging Mechanisms:	Resulting Symptom
Internal Overheating	▪ Removal of the cell from the string. ▪ Venting of the cell
Cell Imbalance (Overcharge/overdischarge	▪ Imbalance of cell voltage levels can cause the cells to age at different rates and affect the internal cell temperature. Improper sizing can also cause similar symptoms.
Lithium Plating	▪ Results from too deep of a discharge with too fast of a recharge repetitively, ▪ When charged at too low of a temperature.
Dendrite/Lithium Deposition	▪ Internal short circuit of a cell
Active Material Instability	▪ **Overtemperature resulting in disconnection**

Lithium ION Battery Technology- *Limitations*

Special Considerations:

- Humidity (Operational and Storage)
- Storage Limitations
- Code Enforced Allowable Quantities
- Clearance for Fire Code Requirement
- Shipping
- Proprietary Software for BMS
- Cost
- Best value for short duration discharges

Lead Acid Battery Technology- *Performance Rating*

- ***Watt-Hours (Wh) vs. Ampere-Hour (Ah)***

Discharge Data at 25°C

EODV = 1,75V/ volts per cell — Discharge current in **Amps (A)**

1'	30'	40'	50'	1 h	2 h	3 h	4 h	5 h	6 h	7 h	8 h	9 h	10 h
162	72	66	60	55	36	27	22	19	17	15	13	12	11
230	108	98	90	83	54	40	32	28	25	22	20	18	17
284	144	131	120	110	72	53	43	37	33	29	26	24	23
338	179	164	151	137	90	67	54	46	41	36	33	30	29
386	215	197	180	165	108	80	65	55	49	43	39	36	35
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Discharge Time (in hours)

Discharge Current (in amperes)

End of Discharge Voltage

Typical lead acid battery discharge data is based on **"Ampere-Hours".**






Lead Acid Battery Technology- *Performance Rating*

- ***Ampere-Hour (Ah)***

Discharge Data at 25^{0}C

EODV = 1,75V/ volts per cell — Discharge current in **Amps (A)**

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386	215	197	180	165	108	80	65	55	49	43	39	36	35
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Discharge Time (in hours)

Discharge Current (in amperes)

Historically, stationary lead acid or nickel cadmium battery "nameplate" capacity has been characterized by capacity . Units of measure are in "ampere-hours".

Formula: **Discharge Time (H) x Discharge Current (A) = Capacity (Ampere-Hour)**

Example: **10 (Hour) x 23 (amps) = 230 Ah**






Lead Acid Battery Technology- *Performance Rating*

▪ ***Useable energy vs. rate of discharge***

EODV = 1,75V/ volts per cell Discharge current in **Amps (A)**

1'	30'	40'	50'	1 h	2 h	3 h	4 h	5 h	6 h	7 h	8 h	9 h	10 h
162	72	66	60	55	36	27	22	19	17	15	13	12	11
230	108	98	90	83	54	40	32	28	25	22	20	18	17
284	144	131	120	110	72	53	43	37	33	29	26	24	23
338	179	164	151	137	90	67	54	46	41	36	33	30	29
386	215	197	180	165	108	80	65	55	49	43	39	36	35
401	252	232	213	194	128	96	80	69	63	55	48	46	41

Discharge Time (in hours)

Discharge Current (in amperes)

Comparing the capacity removed at the (2) rates:

<u>For a 30-minute discharge:</u> **30 (min) x $\frac{1\text{ (Hr)}}{60\text{ (min)}}$ x 144 (amps) = 72 Ah**

<u>For 10-hour discharge:</u> **10 (Hr) x 23 (amps) = 230 Ah**

The slower you discharge a battery, the greater the energy delivered.



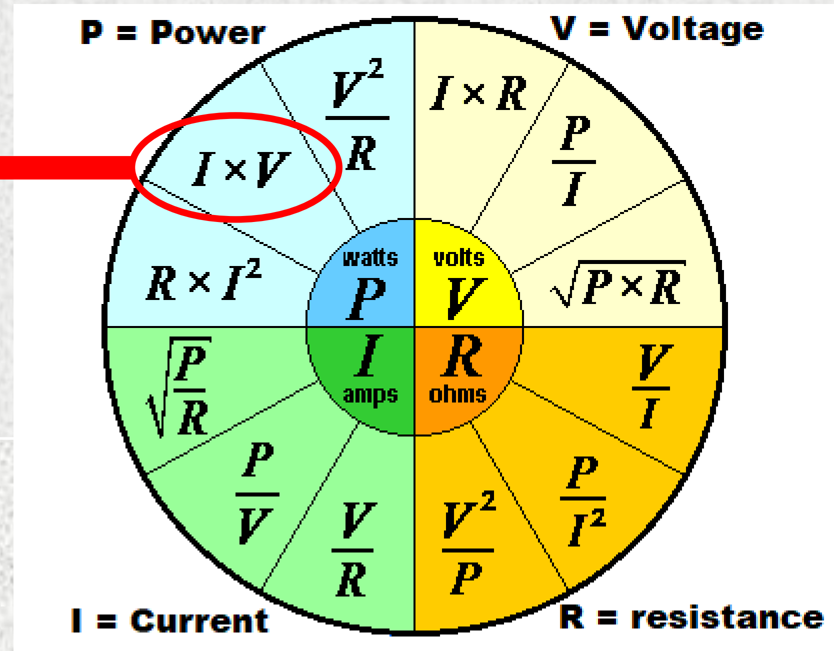



Lithium ION Battery Technology- *Performance*

- ***Watt-Hours (Wh) vs. Ampere-Hour (Ah)***

V x I = P

Voltage (V) x Current (A) = Power (W)



Power: **The <u>rate</u> at which energy is transferred.**

Watt: **One Joule/second**






▪ Lithium ION Battery Technology- *Performance*

▪ ***Watt-Hours (Wh)***

Lithium ion manufacturers use "Watt-Hours" (WH) to characterize battery capacity in order to highlight *energy density*. We consider:

- **Average Voltage (Volts),**
- **Time (Runtime in Hours),**
- **Discharge Current (Amps)**

(V x I) x T = Energy Removed

Formula: **Volts x Ampere-hours = Watt-Hours Ampere-Hour**

Voltage (nominal volts) x Discharge Time (in hours) x Discharge Current (in amperes) = Wh

Example: **3.6 Volts x 42 Ah = 151 Wh**

IFC 2018 chapter 1206.2 and NFPA-1 chapter 52
MAXIMUM ALLOWABLE QUANTITIES (MAQ)

BATTERY TECHNOLOGY	Maximum Allowable Quantity	Group H Occupancy
Lead Acid **(All Types)**	**Unlimited**	**N/A**
Nickel Cadmium	**Unlimited**	**N/A**
Lithium, (All Types)	**600 kWh**	**Group H-2**
Sodium, **(All Types)**	**600 kWh**	**Group H-2**
Flow Batteries	**600 kWh**	**Group H-2**
Other Batteries	**200 kWh**	**Group H-2 ***

Exceeding these levels means the facility has to be reclassified as a "**High Hazard Occupancy**".

International Fire Code (IFC)- developed and updated by review of proposed changes submitted by code enforcement officials, industry representatives, design professionals and other interested parties.

IFC 2018 1206.2 and NFPA-1 MAXIMUM ALLOWABLE QUANTITIES (MAQ)		
BATTERY TECHNOLOGY	**Maximum Allowable Quantity**	**Group H Occupancy**
Lithium, (All Types)	600 kWh	Group H-2

Example: 750 KVA/750 KW UPS for 15 minutes (no aging factor, no design margin, no temperature derating applied).

$$750\text{ kW} \times 15\text{ min} \times \frac{1\text{ hour}}{60\text{ minutes}} = 187.5\text{ KWh}$$

600 KWh / 187.5 kWh = 3.2 → Maximum # of UPS Modules: 3

ARCHITECTURAL CONSIDERATIONS AND FIRE PROTECTIVE MEASURES OF GROUP H-2 OCCUPANCY AND FOR MAQ MUST BE CONSIDERED. The AHJ can determine the requirement to be Group H-2 if the battery represents a significant fire hazard or thermal

IFC 2021 chapter 12 and NFPA-1 chapter 52 MAXIMUM ALLOWABLE QUANTITIES (MAQ) FOR A SINGLE STRING/ARRAY	
BATTERY TECHNOLOGY	**Maximum String Allowable Quantity**
Lead Acid **(All Types)**	**70 KWh**
Nickel Cadmium	**70 KWh**
Lithium, (All Types)	**20 KWh**
Sodium, **(All Types)**	**20 KWh**
Flow Batteries	**20 KWh**
Other Batteries	**10 KWh**

Exceeding these levels means the facility has to be reclassified as a "**High Hazard Occupancy**".

International Fire Code (IFC)- developed and updated by review of proposed changes submitted by code enforcement officials, industry representatives, design professionals and other interested parties.

So……What has changed?

1206.2.8.3 Stationary battery arrays. Storage batteries, prepackaged stationary storage battery systems and pre-engineered stationary storage battery systems shall be segregated into stationary battery arrays not exceeding 50 kWh (180 megajoules) each. Each stationary battery array shall be spaced not less than 3 feet (914 mm) from other stationary battery arrays and from walls in the storage room or area. The storage arrangements shall comply with Chapter 10.

Exceptions:

1. Lead acid and nickel cadmium storage battery arrays.
2. Listed pre-engineered stationary storage battery systems and prepackaged stationary storage battery systems shall not exceed 250 kWh (900 megajoules) each where approved by the *fire code official*.
3. The *fire code official* is authorized to approve listed, pre-engineered and prepackaged battery arrays with larger capacities or smaller battery array spacing if large-scale fire and fault condition testing conducted or witnessed and reported by an approved testing laboratory is provided showing that a fire involving one array will not propagate to an adjacent array, and be contained within the room for a duration equal to the fire-resistance rating of the room separation specified in Table 509 of the International Building Code.

So……What has changed?

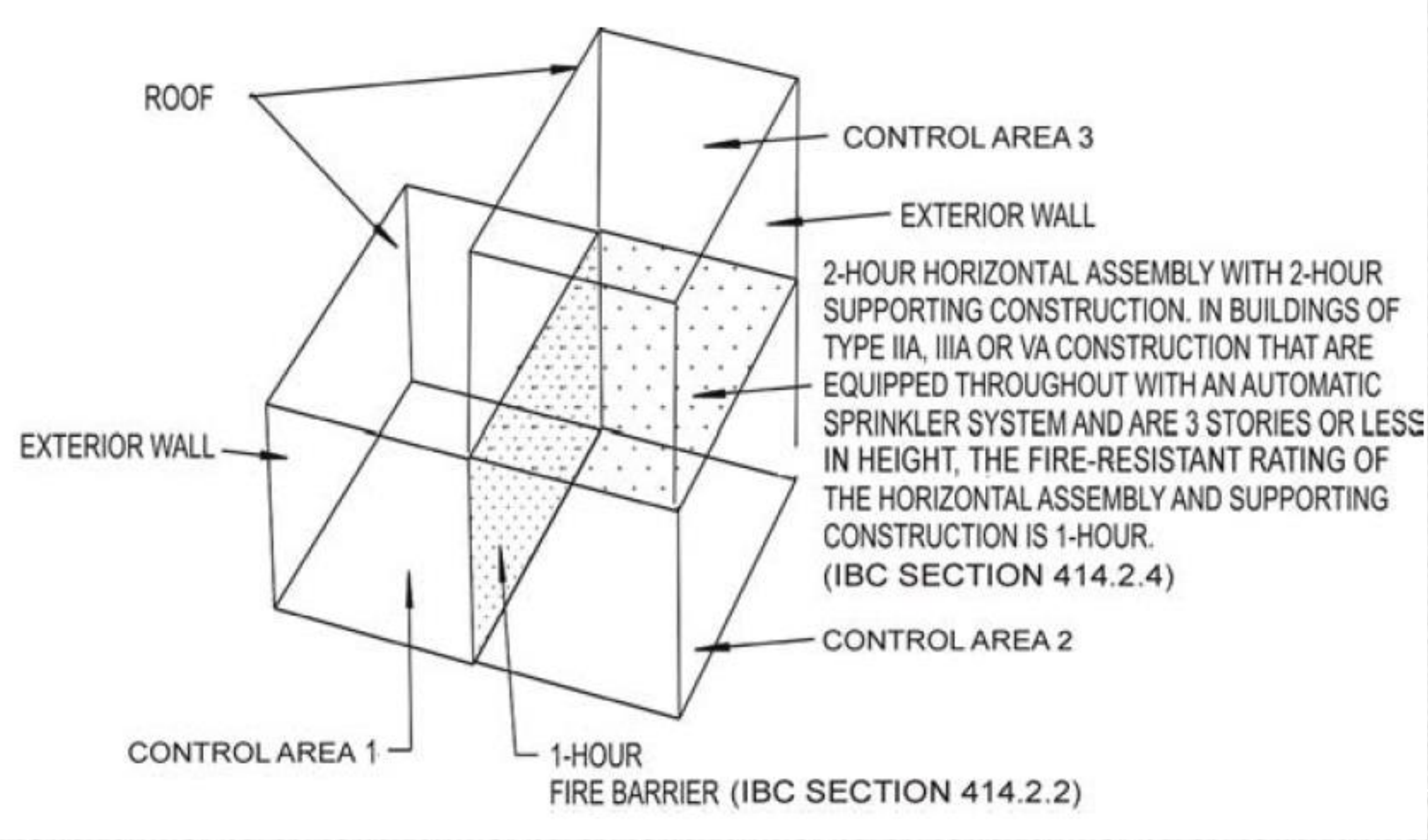
UL 9540A (TESTING METHOD For EVALUATING THERMAL RUNAWAY FIRE PROPOGATION IN BATTERY ENERGY STORAGE SYSTEMS)

- Heat Release Rate
- Gas Generation Composition
- Explosions/Flying Debris
- Target Unit & Wall Surface Temps
- Target Unit & Wall Surface Heat Flux

Note: This is NOT a standard but is currently referenced in NFPA 855.

Where is the battery to be installed?

CONTROL AREA



Lithium ION Battery Technology- *Performance*

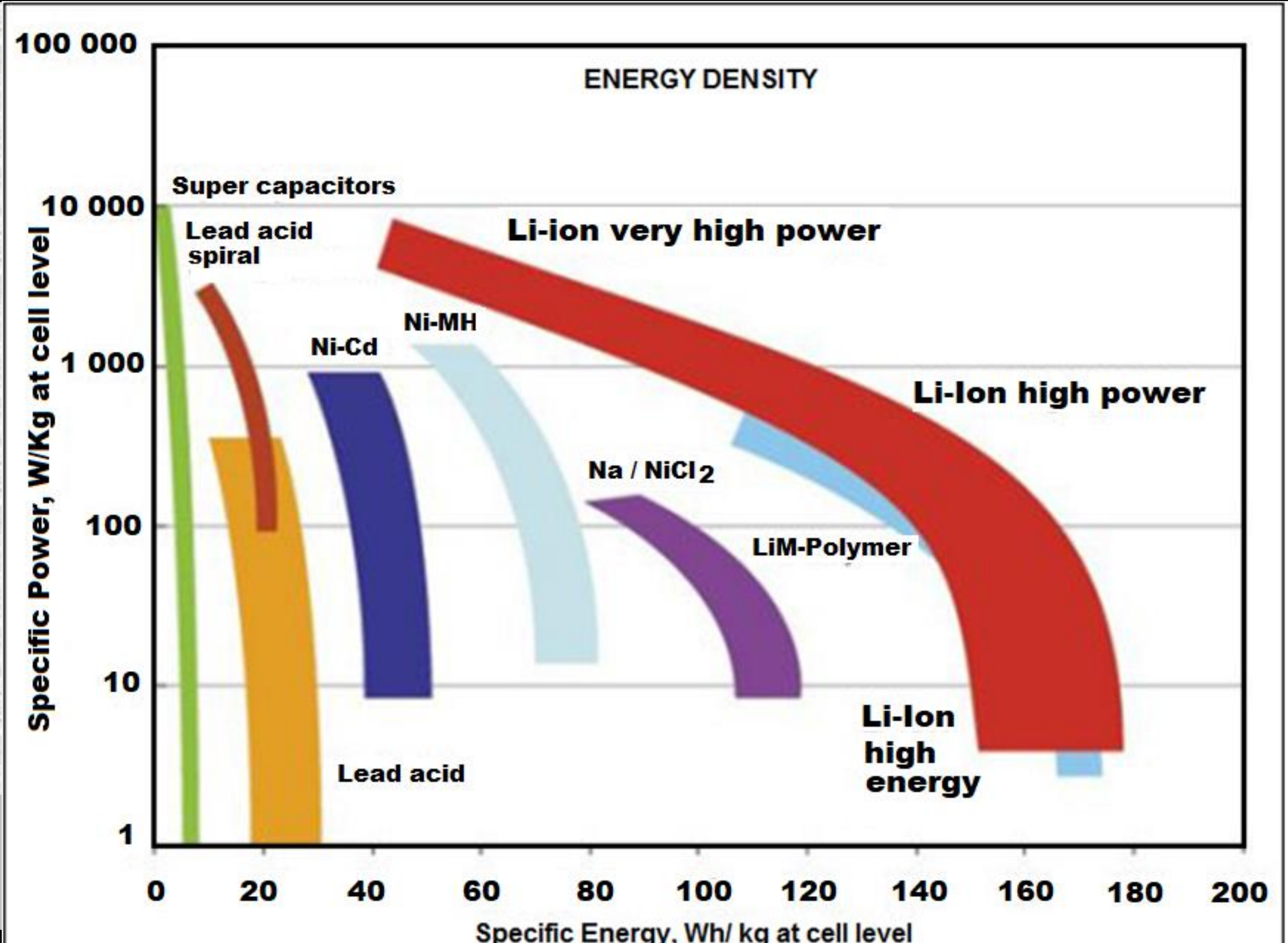
Performance Topics:

- Capacity- Watt-Hours (Wh) vs. Ampere-Hour (Ah)
- High Energy Density
- Fast Recharge
- Flat Discharge Curve
- Predicted Float Life Curve (Shelf Life)
- Cycle Life Vs. Float Life
- Temperature Tolerance
- Reliability
- Safety






Lithium ION Battery Technology - Energy Density



Lithium ION Battery Technology- *Performance*

PREVALENT LION Chemistries:

Station Battery Technology	Chemistry
LTO Lithium Titanate Oxide	$Li_4Ti_5O_{12}$ / $6LiCoO_2$
LFP Lithium Iron Phospate (LFP/LiFePO4)	LiFePO4 / LiC_5
SLFP Super Lithium Iron Phosphate (LFP / LiFePO4 +NCA	LiFePO4 + LiNiCoAlO2 / LiC_5
NCA Lithium Nickel Cobalt Aluminum Oxide	**LiNiCoAlO2** (9% Co)
NMC Lithium Nickel Manganese Cobalt Oxide	LiNiMnCoO2






▪ LITHIUM ION BATTERY – SPIDER GRAPH

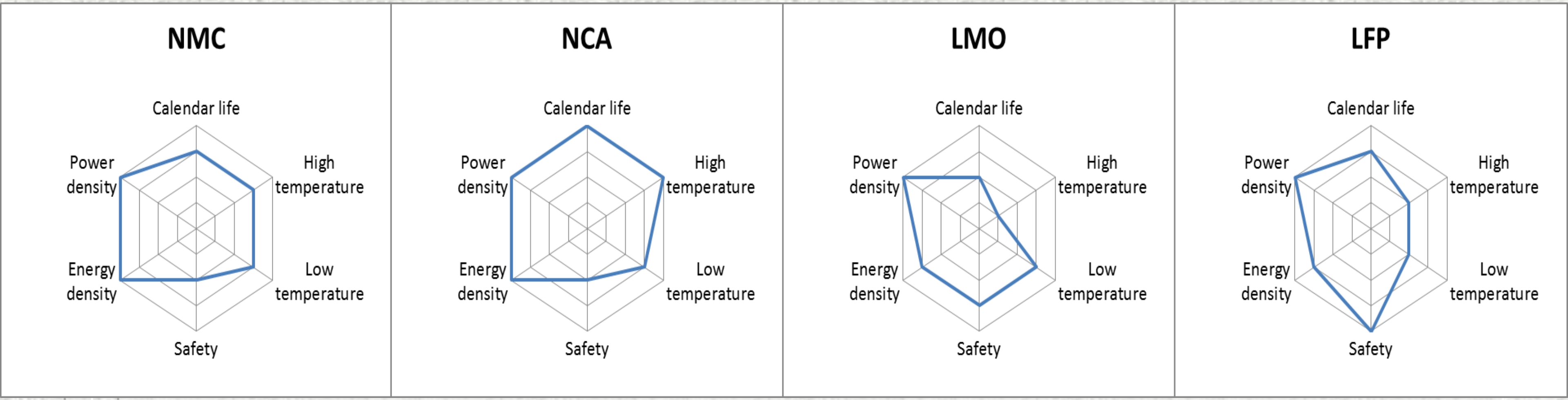


Figure 1

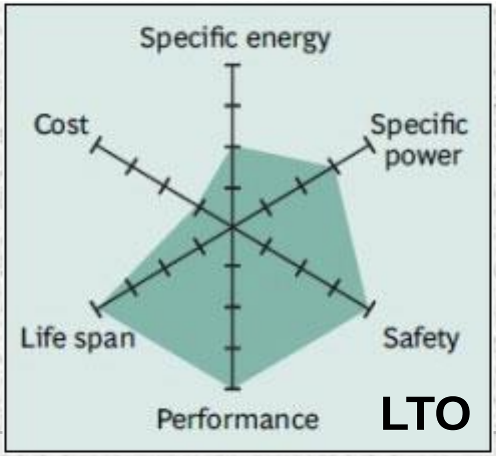


Figure 2

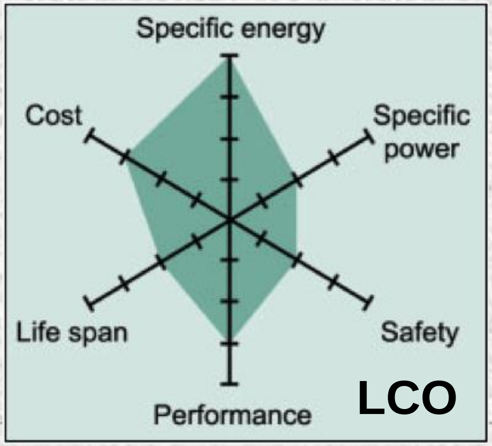
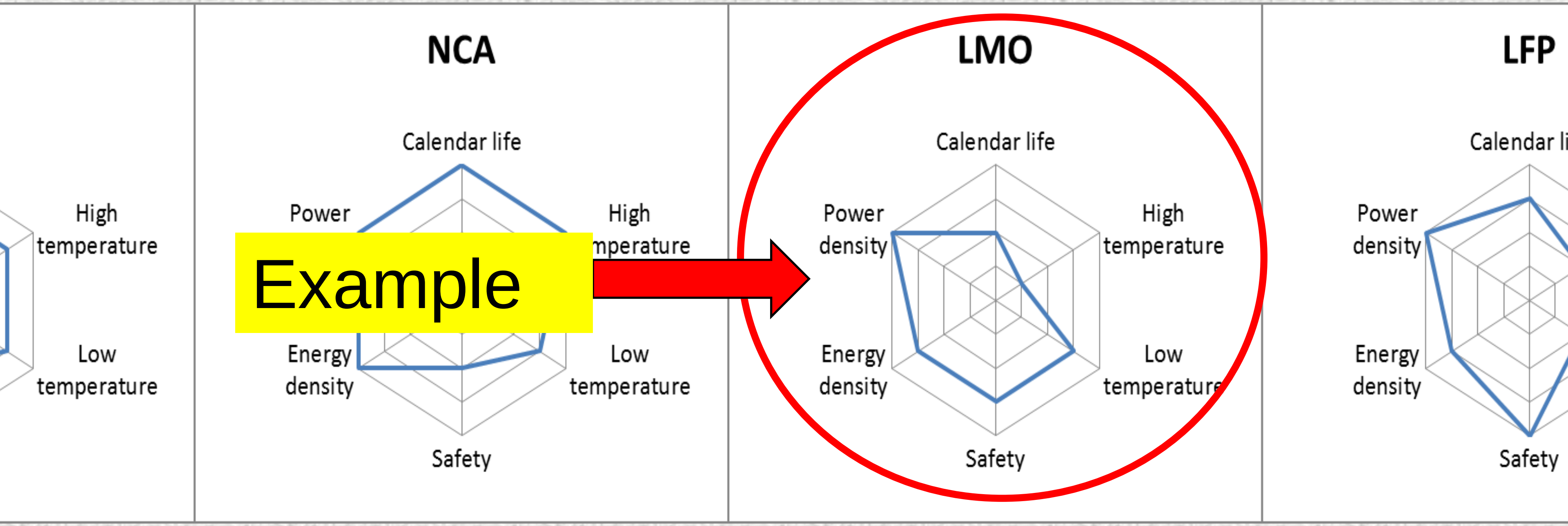


Figure 3

Source for Figure 1 is Battcon paper by Jim McDowell. Fig 1 Fig. 2 and Fig 3 Reference: Battery University Website

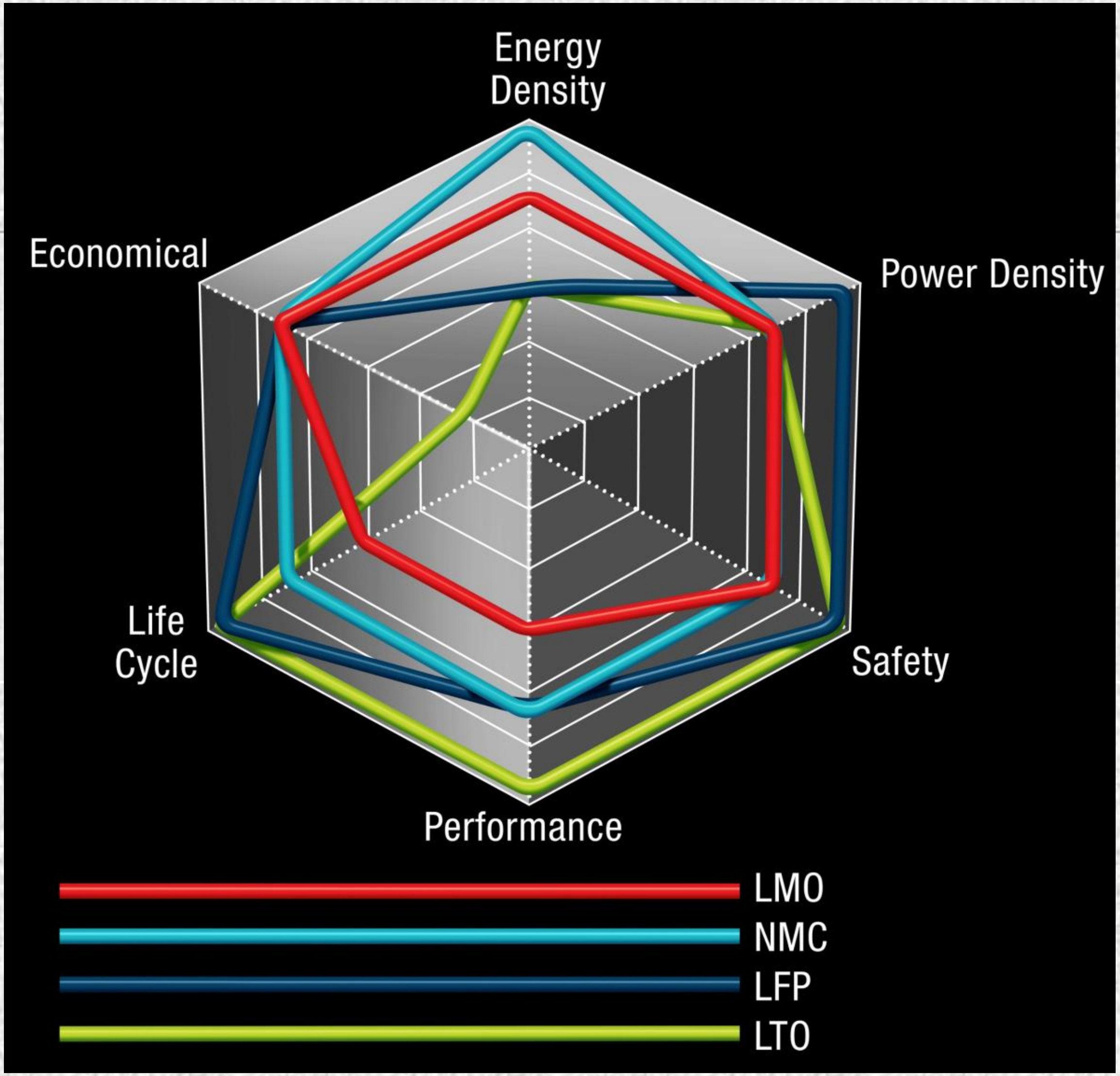
LITHIUM ION BATTERY – SPIDER GRAPH



Feature:	
Power Density:	Very High (almost off the chart)
Life:	Not very good
Hi Temp Operation:	Poor
Energy Density:	Excellent
Safety:	Excellent

Reference: Battery University Website

▪ LITHIUM ION BATTERY – SPIDER GRAPH



Reference: Mitsubishi Electric Website

IEEE WG_1679-1) that is in the process of defining the criteria to be used for the comparison, selection and analysis of the electrical and safety performance criteria.

Lithium Ion Battery- Electrode Configuration

Station Battery Technology	Chemistry	Electrode Construction
LTO Lithium Titanate Oxide	$Li_4Ti_5O_{12}$ / $6LiCoO_2$	Prismatic
LFP Lithium Iron Phospate (LFP/LiFePO4)	LiFePO4 / LiC_5	Cylindrical Jelly-roll
SLFP Super Lithium Iron Phosphate (LFP / LiFePO4 +NCA	**LiFePO4 +** LiNiCoAlO2 / LiC_5	Cylindrical Jelly-roll
NCA Lithium Nickel Cobalt Aluminum Oxide	**LiNiCoAlO2** (9% Co)	Cylindrical Jelly-roll
NMC Lithium Nickel Manganese Cobalt Oxide	LiNiMnCoO2	Cylindrical Jelly-roll

Does cell construction matter for the end-user?

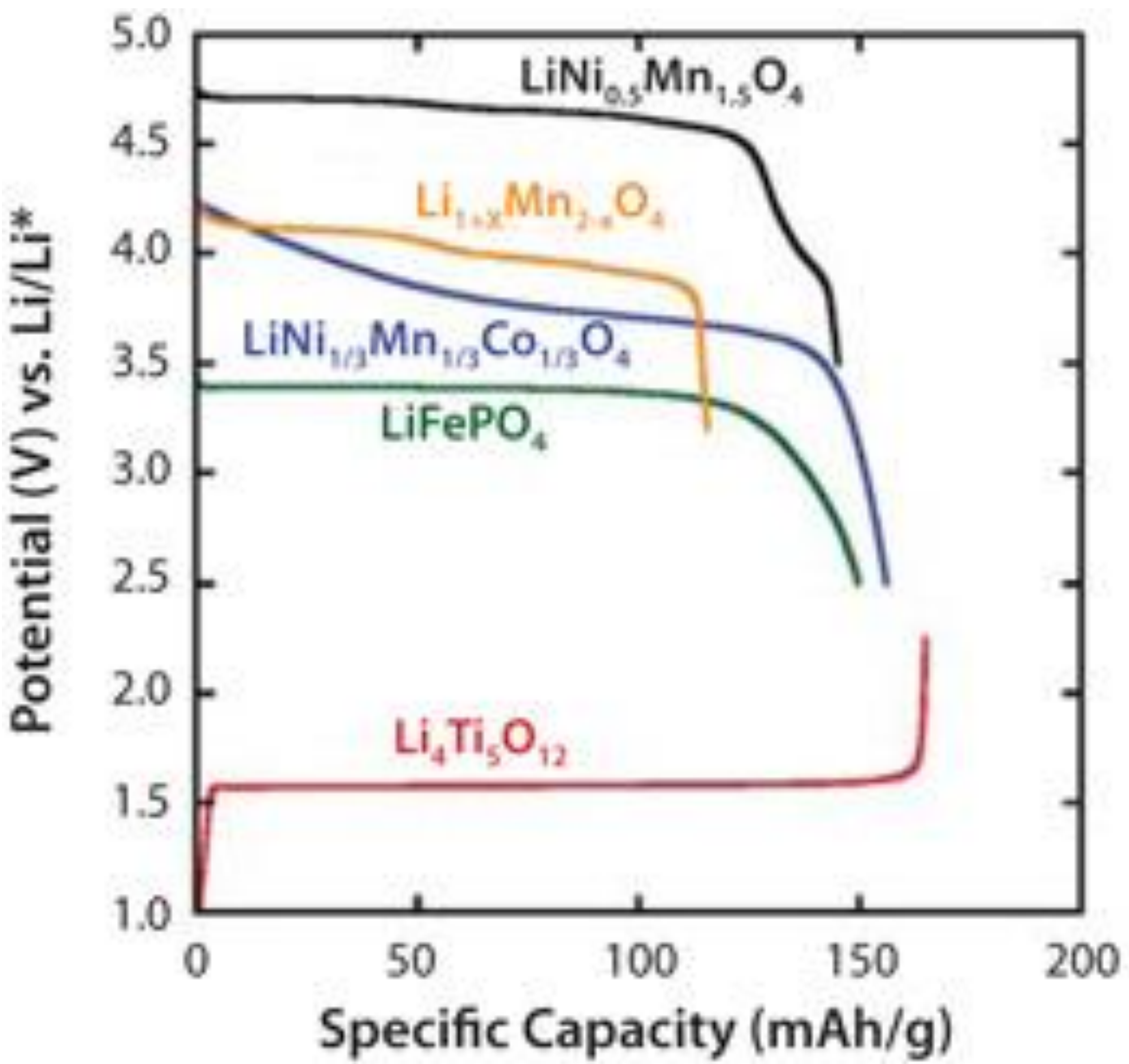
Lithium Ion Battery- *Performance Comparison*

Electrode (Product No.)	Potential vs. Li/Li^+ (V)[A]	Specific Capacity, (mAh/g)	Advantages	Disadvantages
Positive Electrodes				
$LiCoO_2$ (442704)	3.9	140	Performance	Cost and resource limitations of Co, low capacity
$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ (760994)	3.8	180–200	High capacity and voltage, excellent rate performance	Safety, cost and resource limitations of Ni and Co
$LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ (761001)	3.8	160–170	High voltage, moderate safety	Cost and resource limitations of Ni and Co
$LiMn_2O_4$ variants (725129)	4.1	100–120	Low cost and abundance of Mn, high voltage, moderate safety, excellent rate performance	Limited cycle life, low capacity
$LiFePO_4$ (759546)	3.45	170	Excellent safety, cycling, and rate capability, low cost and abundance of Fe, low toxicity	Low voltage and capacity (substituted variants), low energy density
Negative Electrodes				
Graphite (698830)	0.1	372	Long cycle life, abundant	Relatively low energy density; inefficiencies due to Solid Electrolyte Interface formation
$Li_4Ti_5O_{12}$ (765155)	1.5	175	"Zero strain" material, good cycling and efficiencies	High voltage, low capacity (low energy density)

A. Average

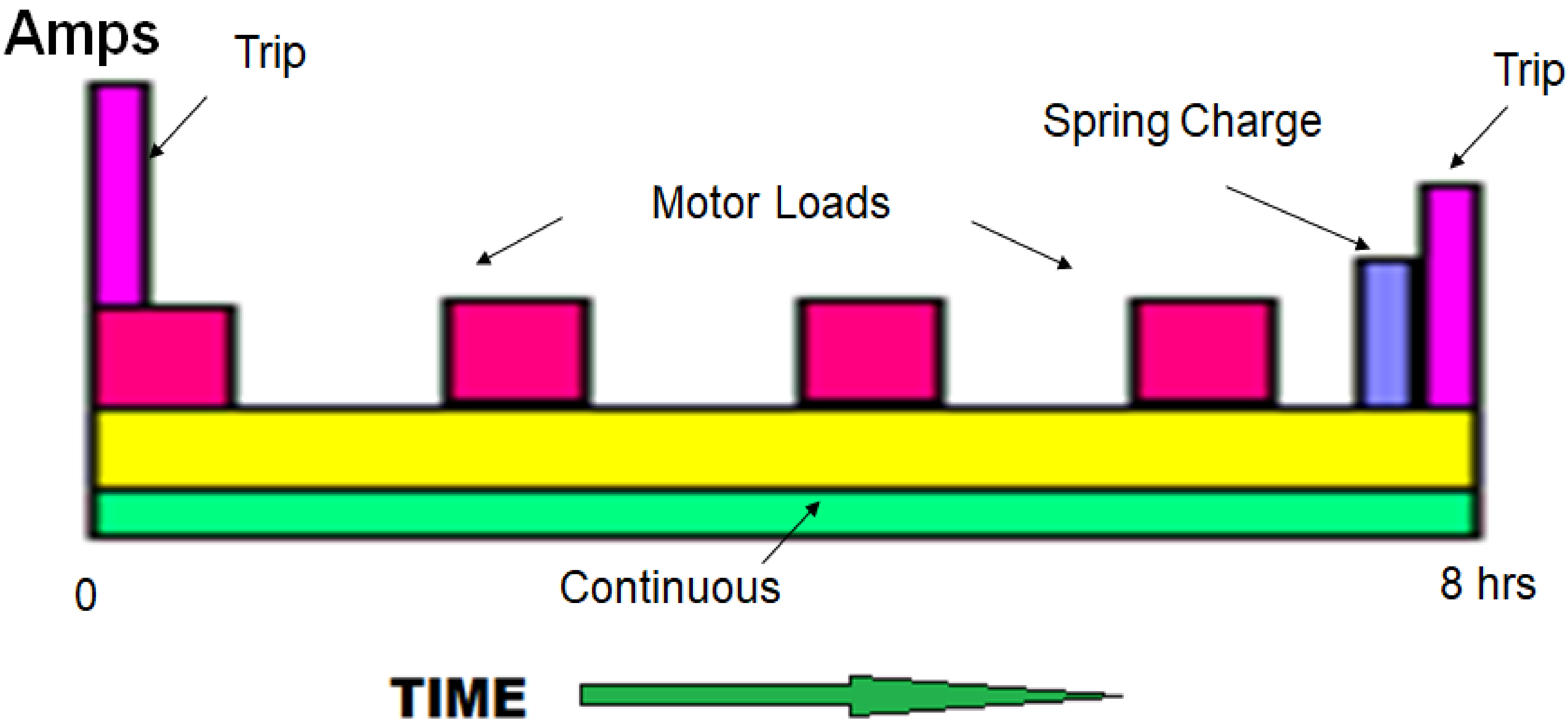
Does technology really matter for stationary battery performance?

Lithium Ion Battery- *Performance Comparison*



Does technology really matter for stationary battery performance?

GENERATION PLANT Load Profile- 240 VDC



- Continuous UPS Load
- Continuous Load (controls, LEDs, relay...)
- Switchgear Close Coil/ Recharge
- Circuit Switch Trip Load
- DC Lube Oil Pump Motor Load

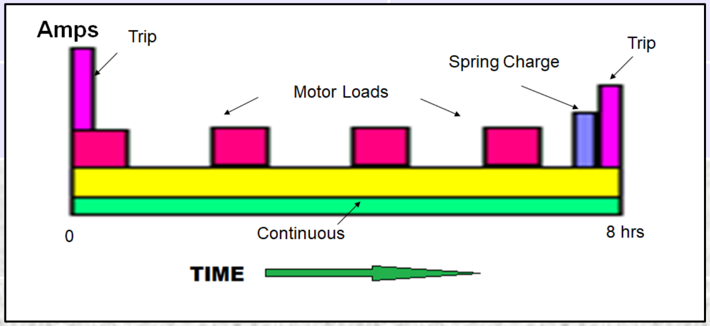
Generation Plant Example- 240VDC (50KW 8 Hours)

Raw Material	Price per Pound (US$)
Titanate Oxide	$25.70
Cobalt Oxide	$14.52
Lithium Carbonate	$7.36
Nickel	$5.60
Lead (New)	$0.92
Lead (Scrap)	$0.75

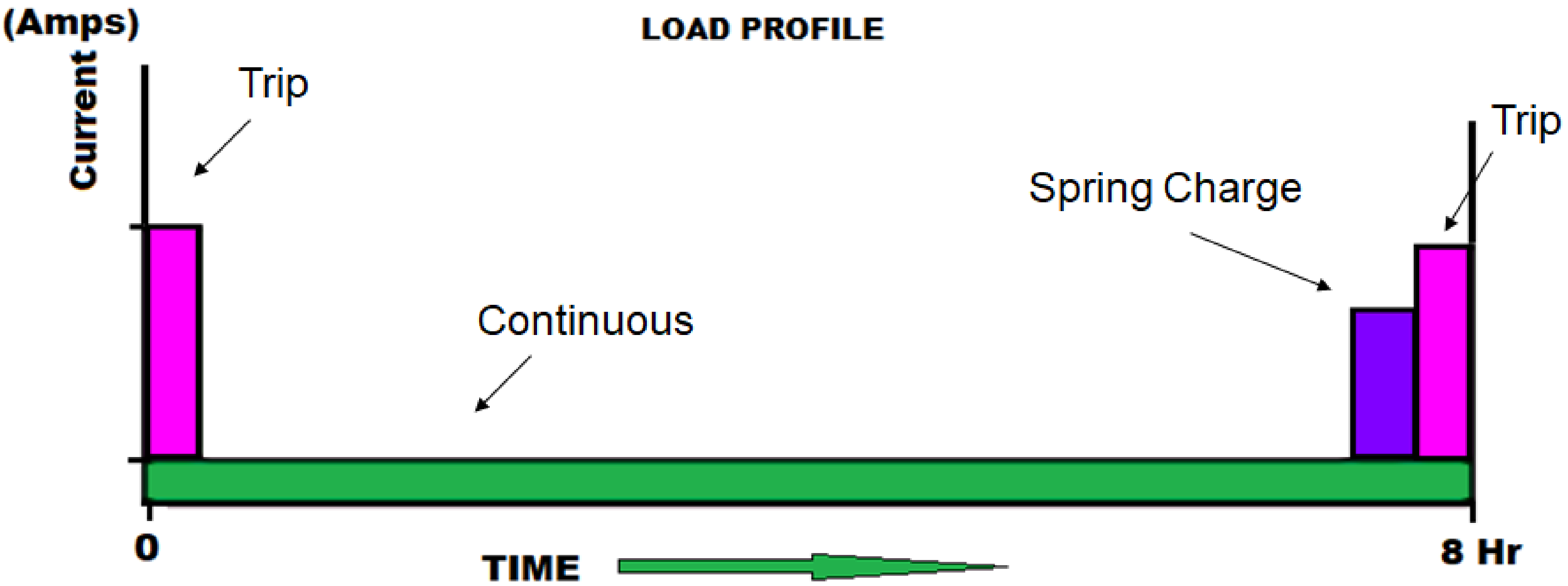
?? = transparency

Generation Plant Example- 240VDC (50KW 8 Hours)

50KWB GENERATION PLANT UPS APPLICATION			
Battery Type	**Cost**	**Battery Type**	**Cost**
Flooded Pb Calcium Faure'	$165,600	VR Pb antimony Gel Faure'	$384,200
Flooded Pb antimony Faure'	$162,680	Flooded VR Nicad	$212,689
Flooded Plante'	$179,500	Flooded Nicad Pocket plate	$205,564
Flooded Pb Selenium	$135,360		
Flooded lead antimony tubular	$160,720	Flooded NicadPBE	$256,556
VRLA calcium	$184,024	Flooded Nicad Fiber	$233,073
Lithium LFP	$288,000		
Lithium Titanate	$252,000		



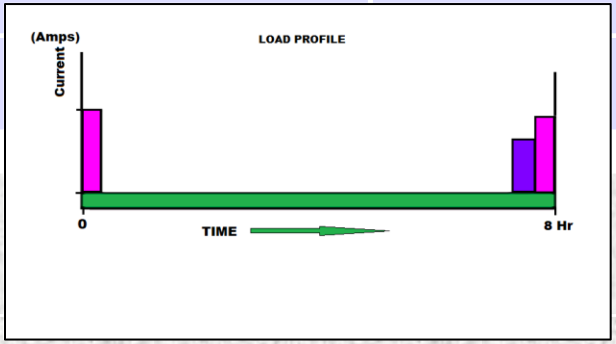
SUBSTATION Switchgear Load Profile- 120 VDC



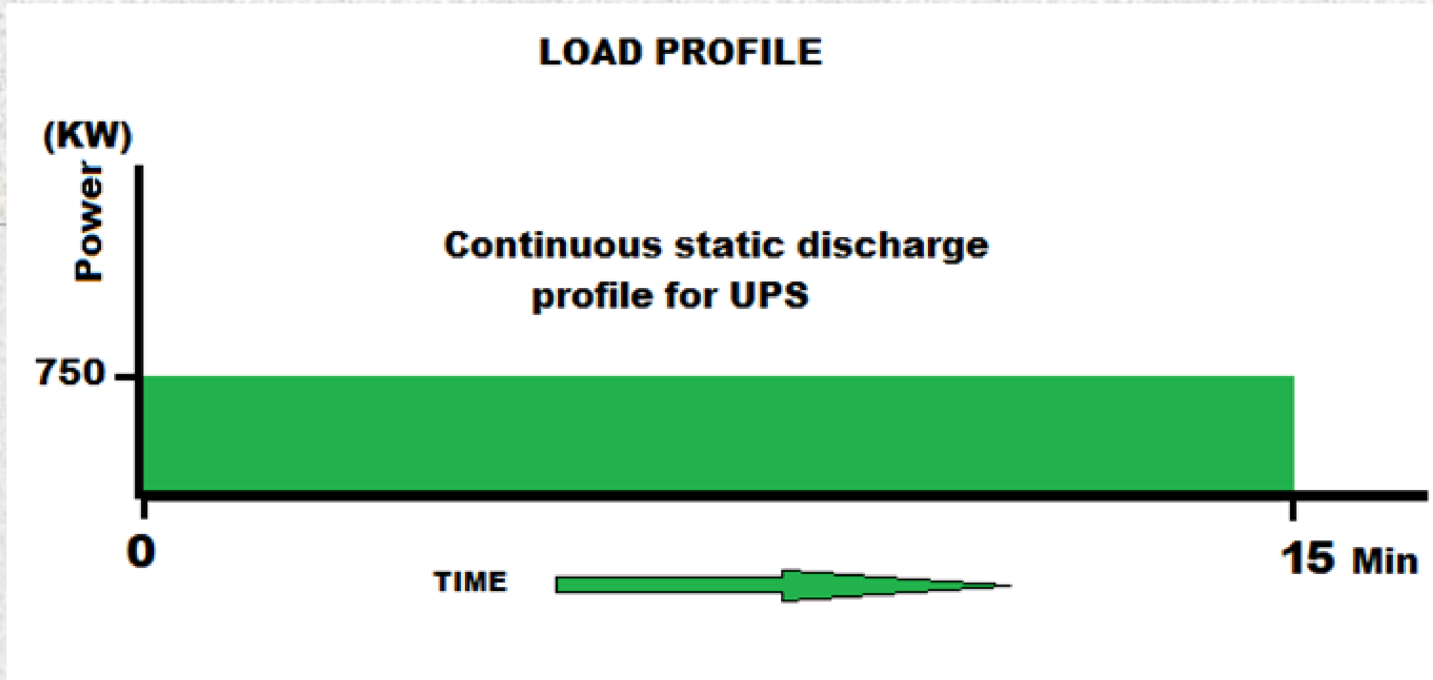
Common worst case scenario is for all breakers to trip simultaneously at the beginning of the outage, and then to trip again at the end.

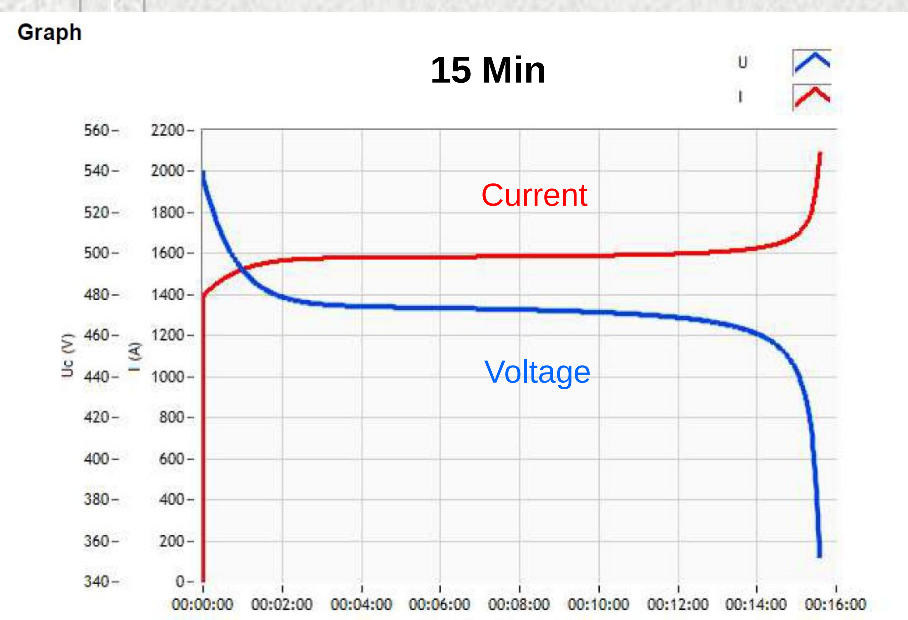
Substation Example- 120VDC

Battery Type	Cost	Battery Type	Cost
Flooded Pb Calcium Faure’	$7,844	VR Pb antimony Gel Faure’	$6,070
Flooded Pb antimony Faure’	$7,643	Flooded VR Nicad	$12,595
Flooded Plante’	$18,842	Flooded Nicad Pocket plate	$5,812
Flooded Pb Selenium	$6,700		
Flooded lead antimony tubular	$7,800	Flooded Nicad PBE	$7,985
VRLA Calcium 10- Yr	$2,784	Flooded Nicad Fiber	$6,378
Lithium Titanate	$14,000		
SLFP	$12,224		



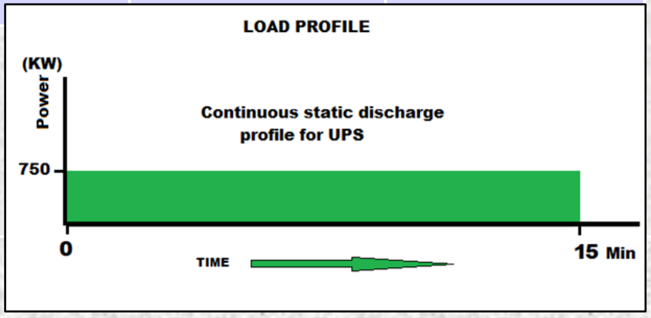
DATA CENTER UPS Load Profile- 480 VDC





Lithium Ion Battery- 480V 750kWB 15-Min UPS

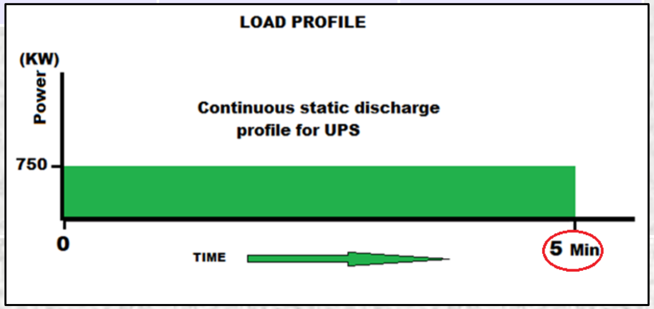
UPS APPLICATION 480VDC 15 Minute Battery @ 750KWB							
Technology	**# of Strings**	**# of Cabinets**	**Length (In)**	**Width (In)**	**Height (In)**	**Total Weight (lbs)**	**Cost**
Flooded NICAD	1	2+2T Racks	1490	25	76	46,800	$390,000
VLA Calcium	1	3T Racks	510	35	78	59,916	$225,000
VLA Selenium	1	2+2T Racks	570	32	82	70,640	$258,000
VRLA (10-Yr)	6	6 cab	240	29.5	78.7	29,266	$98,266
Lithium NMC	20	20 cab	446	27.2	92.1	28,020	$205,000
Lithium LFP	12	12 cab	288	20.5	84	10,440	$214,800



Lithium Ion Battery- 480V 750kWB 5-Min UPS

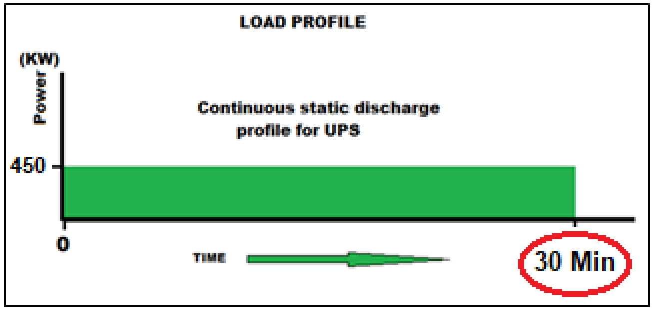
UPS APPLICATION
480VDC 5 Minute Battery @ 750KWB

Technology	# of Str	# of Cab	Length (In)	Width (In)	Height (In)	Total Weight (lbs)	Cost
Flooded NICAD	1	2+2 Racks	1490	25.0	76.0	46,800	$241,000
VLA Calcium	1	3T Racks	816	32	78	42,528	$153,360
VLA Selenium	1	2+2 Racks	570	32	78	45,360	$178,320
VRLA (10-Yr)	4	4 cab	194	33.6	78.7	28,720	$66,250
Lithium LTO	16	8 cab	273	34.1	80.7	15,360	$311,900
Lithium LFP	6	6 cab	144	20.5	84.0	5,220	$107,400

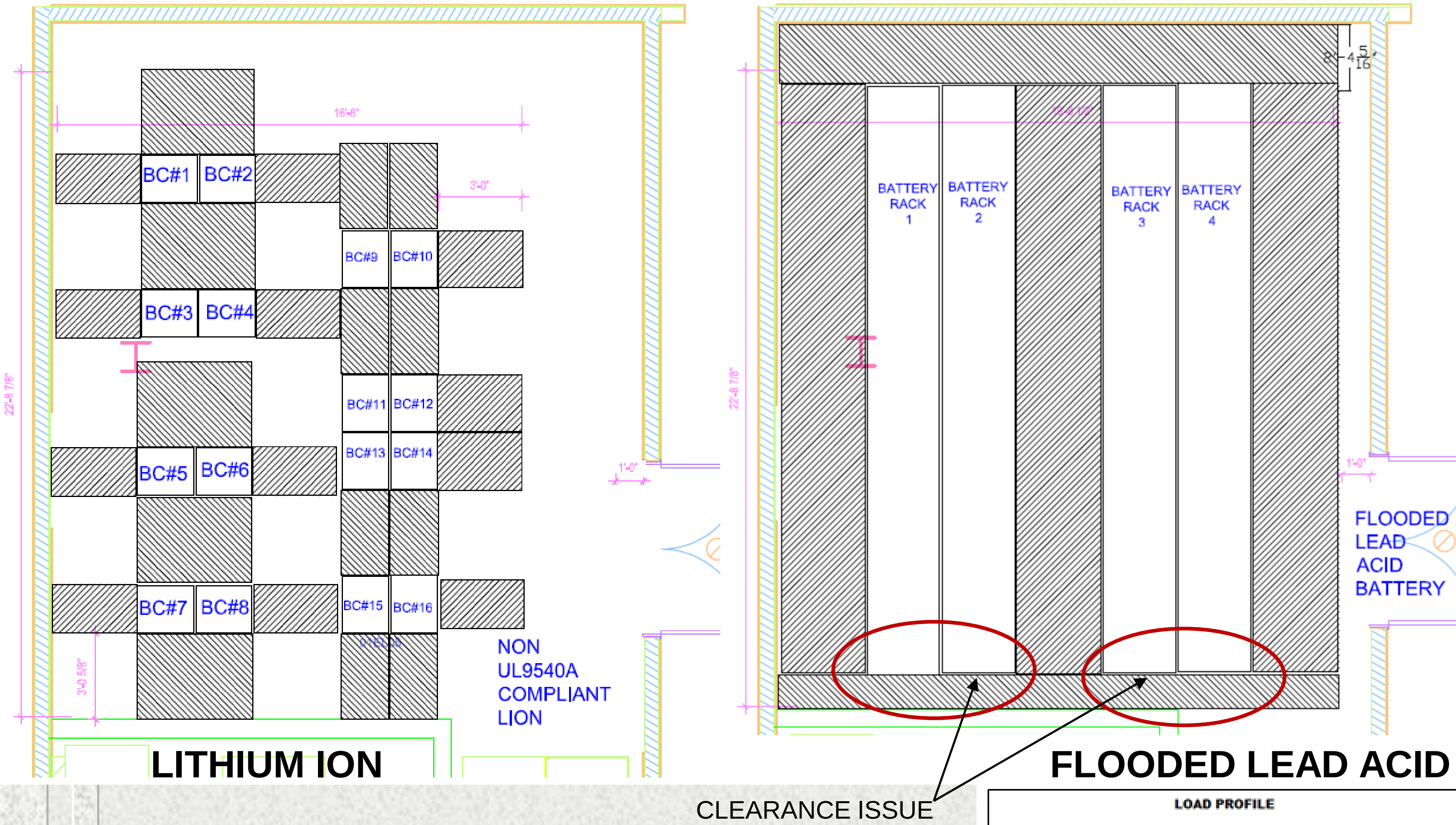


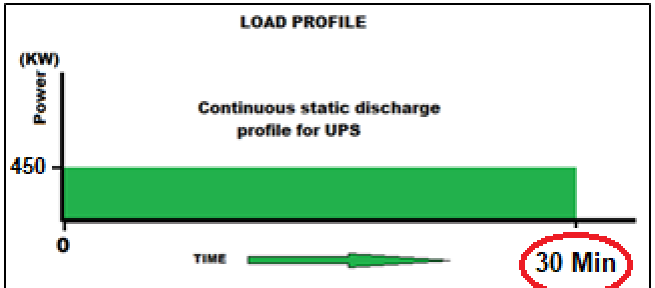
Lithium Ion Battery- 480V 450kWB 30-Min UPS

UPS APPLICATION 480VDC 30 Minute Battery @ 450 KWB							
Technology	**# of Str**	**# of Cab**	**Length (In)**	**Width (In)**	**Height (In)**	**Total Weight (lbs)**	**Cost**
VLA Selenium (Flooded)	1	4 ea 2-Tier Racks	996	35	84	67,440	$221,040
VRLA (10-Yr)	4	4 cab	194	33.6	78.7	28,720	$142,140
Lithium LTO	24	24 cab	818.4	34.1	80.7	47,820	$1,169,280
Lithium LFP (UL 9540A approved)	16	16 cab	384	20.5	84.0	6,368	$267,017
Lithium LFP (Non- UL 9540A approved)	12	12 cab	288	20.5	84.0	4,776	$236,945

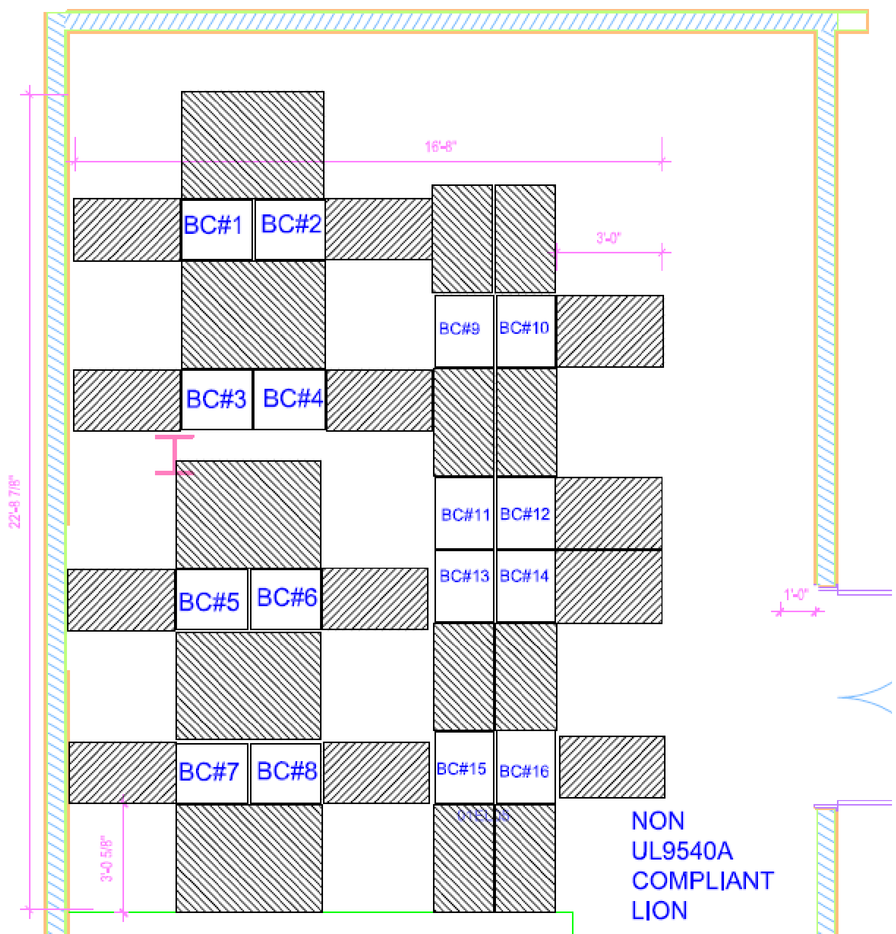


Lithium Ion Battery- 480V 450kWB 30-Min UPS

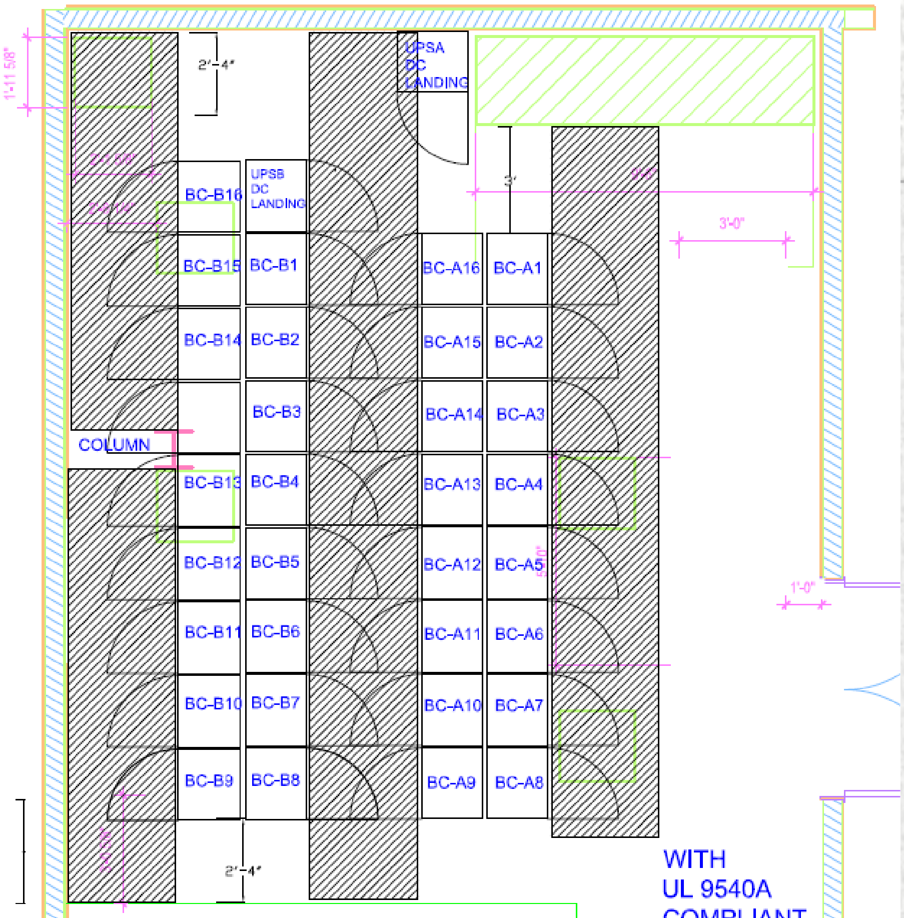




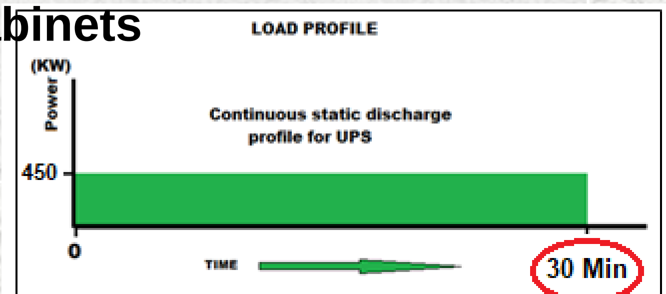
Lithium Ion Battery- 480V 450kWB 30-Min UPS



LITHIUM ION
16 each cabinets



LITHIUM ION
32 each cabinets



Lithium Ion Battery- *Electrode Configuration*

Fig 1

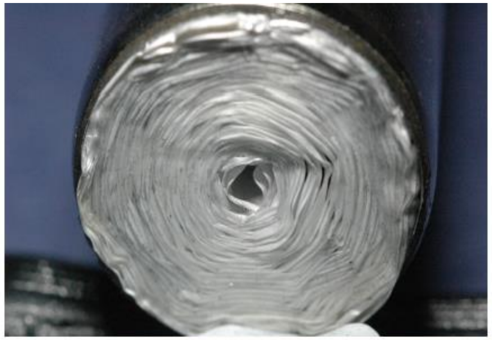


Fig 2

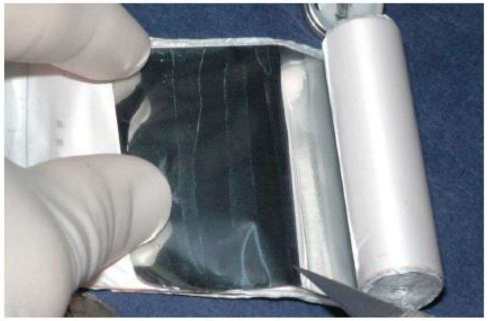


Fig 3

Cylindrical Cell

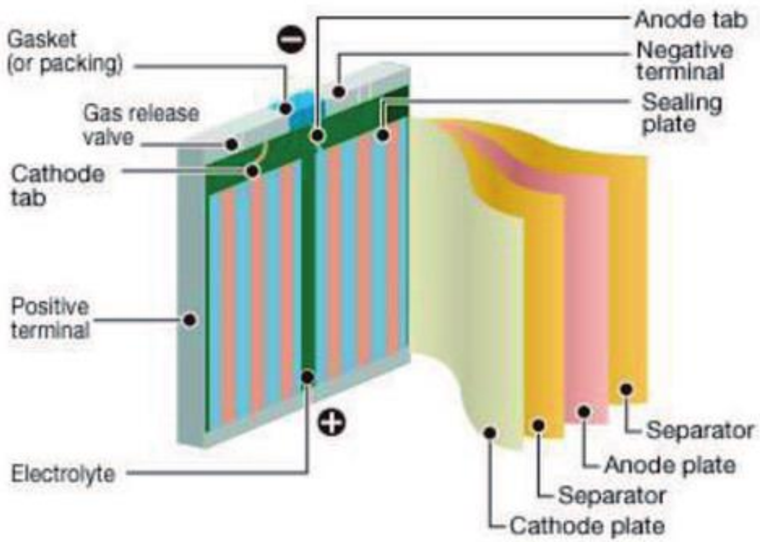


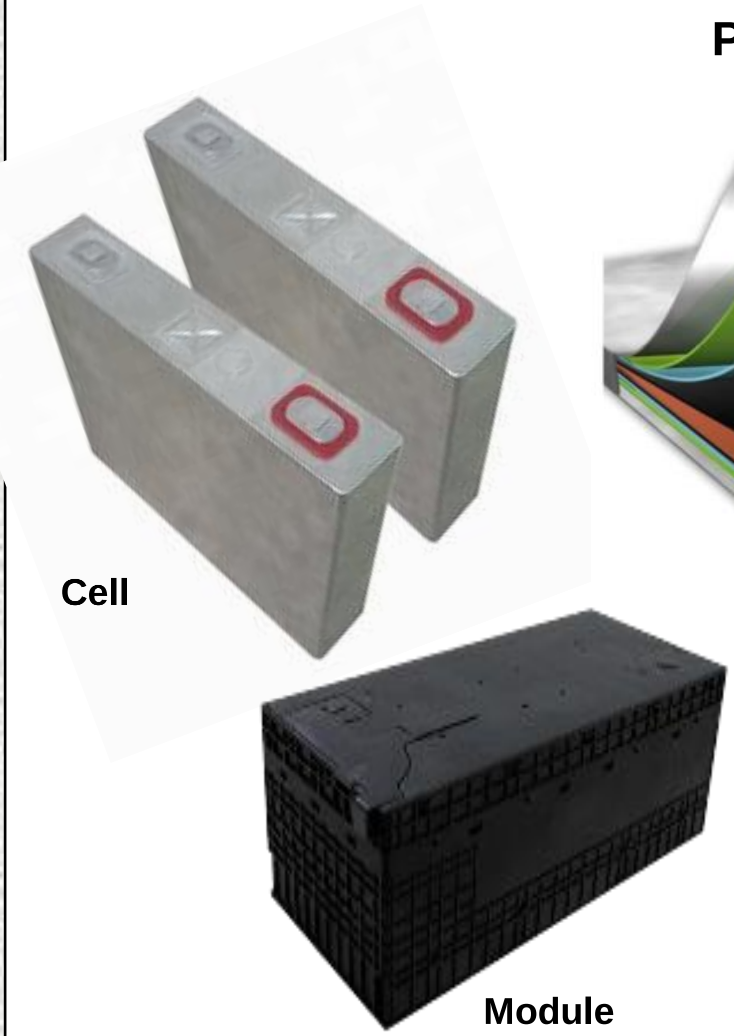
Fig 4

Benefits:

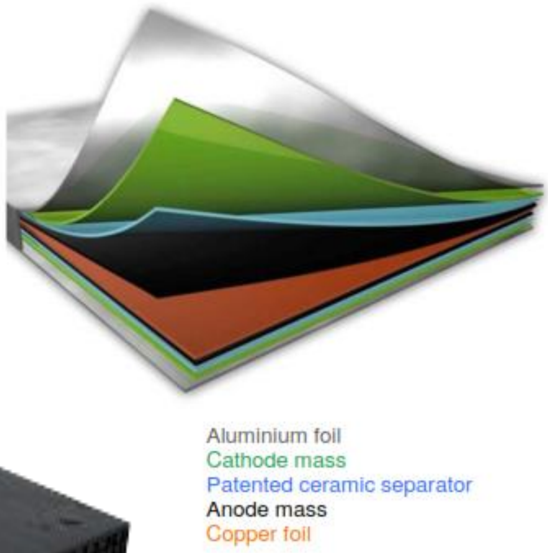
- Good heat dissipation
- Best for high temperature mgmt
- Flexible form factor
- **Lower cost**

Does cell construction matter for the end-user?

Lithium Ion Battery- *Electrode Configuration*

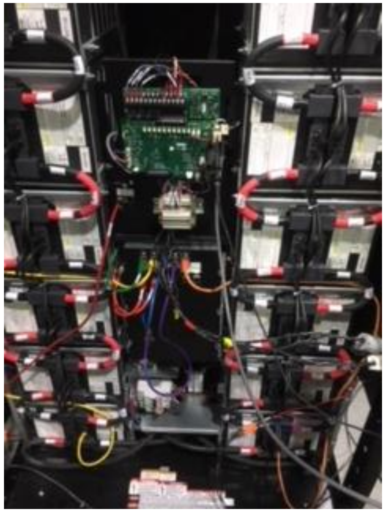


Prismatic Cell



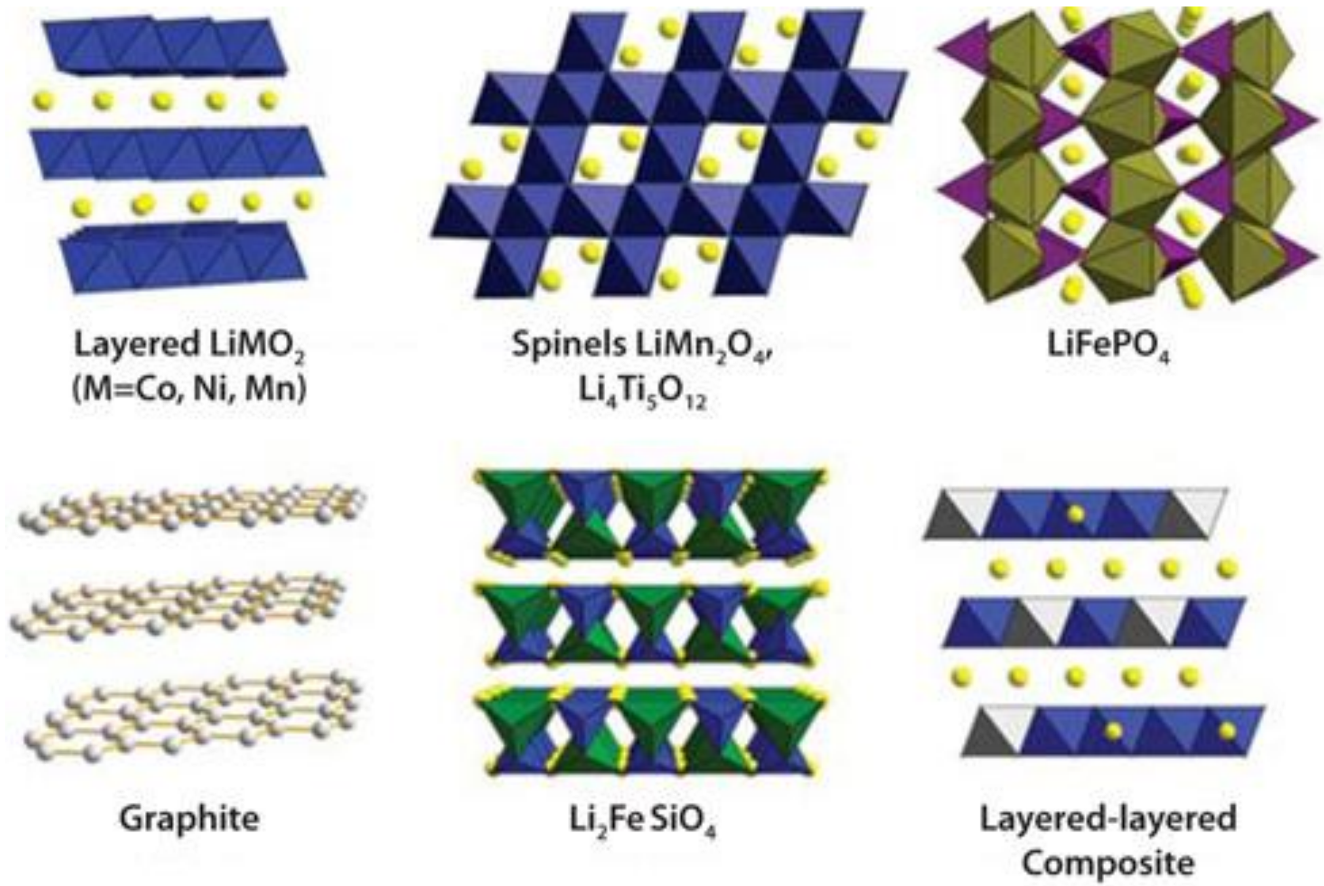
Benefits:

- Good heat dissipation
- Flexible form factor
- **Super-fast charging**
- Less SEI Interface growth with low temp charging
- Less Lithium plating during **cycling**



Does cell construction matter for the end-user?

Lithium Ion Battery- ***Performance Comparison***



Does technology really matter for stationary battery performance?

Lithium Battery Training- Electrolyte

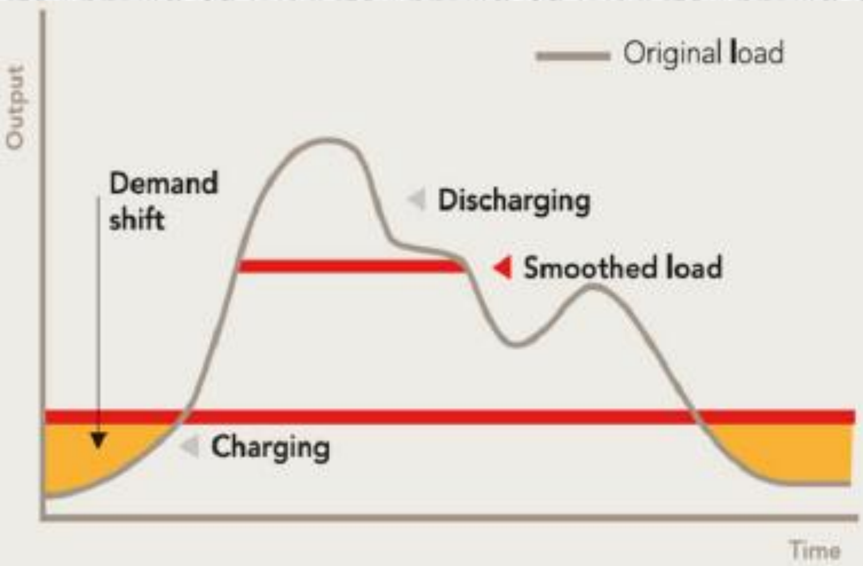
FLASHPOINTS FOR VARIOUS LITHIUM ION ELECTROLYTES

Table 1. Measured flash points, auto-ignition temperatures, and heats of combustion of some typical lithium-ion cell organic electrolyte components

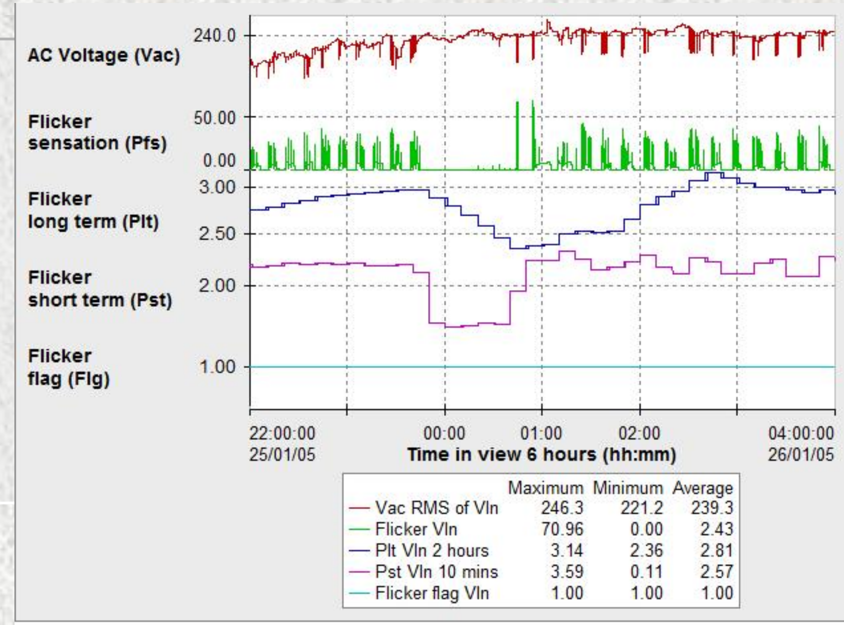
Electrolyte Component	CAS Registry Number	Molecular Formula	Melting Point[25]	Boiling Point[25]	Vapor pressure (torr)[26]	Flash Point[26]	Auto-Ignition Temperature[26]	Heat of Combustion[27]
Propylene Carbonate (PC)	108-32-7	$C_4H_6O_3$	-49°C -56°F	242°C 468°F	0.13 at 20°C	135°C 275°F	455°C 851°F	-20.1 kJ/ml -4.8 kcal/ml
Ethylene Carbonate (EC)	96-49-1	$C_3H_4O_3$	36°C 98°F	248°C 478°F	0.02 at 36°C	145°C 293°F	465°C 869°F	-17.2 kJ/ml -4.1 kcal/ml
Di-Methyl Carbonate (DMC)	616-38-6	$C_3H_6O_3$	2°C 36°F	91°C 195°F	18 at 21°C	18°C 64°F	458°C 856°F	-15.9 kJ/ml -3.8 kcal/ml
Diethyl Carbonate (DEC)	105-58-8	$C_5H_{10}O_3$	-43°C 45°F	126°C 259°F	10 at 24°C	25°C 77°F	445°C 833°F	-20.9 kJ/ml -5.0 kcal/ml
Ethyl methyl carbonate (EMC)	623-53-0	$C_4H_8O_3$	-14°C 6.8°F	107°C 225°F	27 at 25°C	25°C 77°F	440°C 824°F	None available

▪ BATTERY – Cycle Life

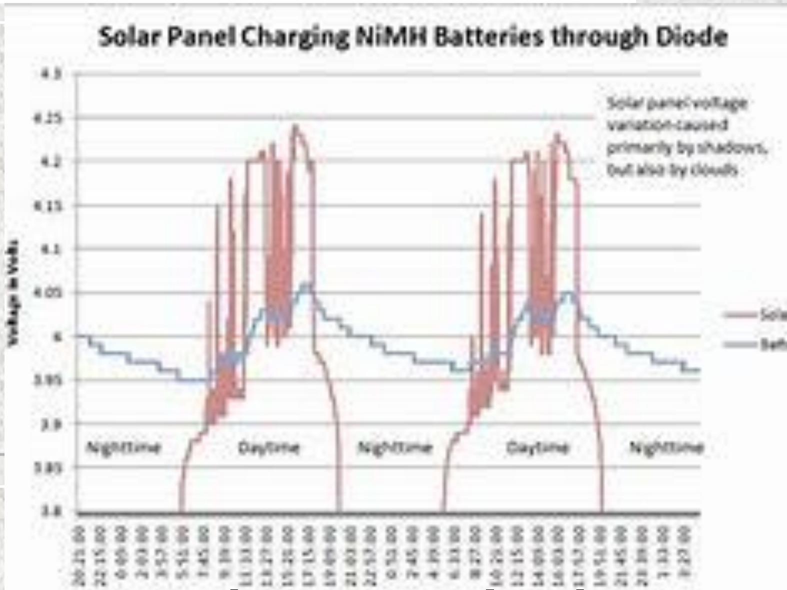
WHEN DOES CYCLE LIFE REALLY MATTER?



Peak Shaving



Flicker



Photovoltaic

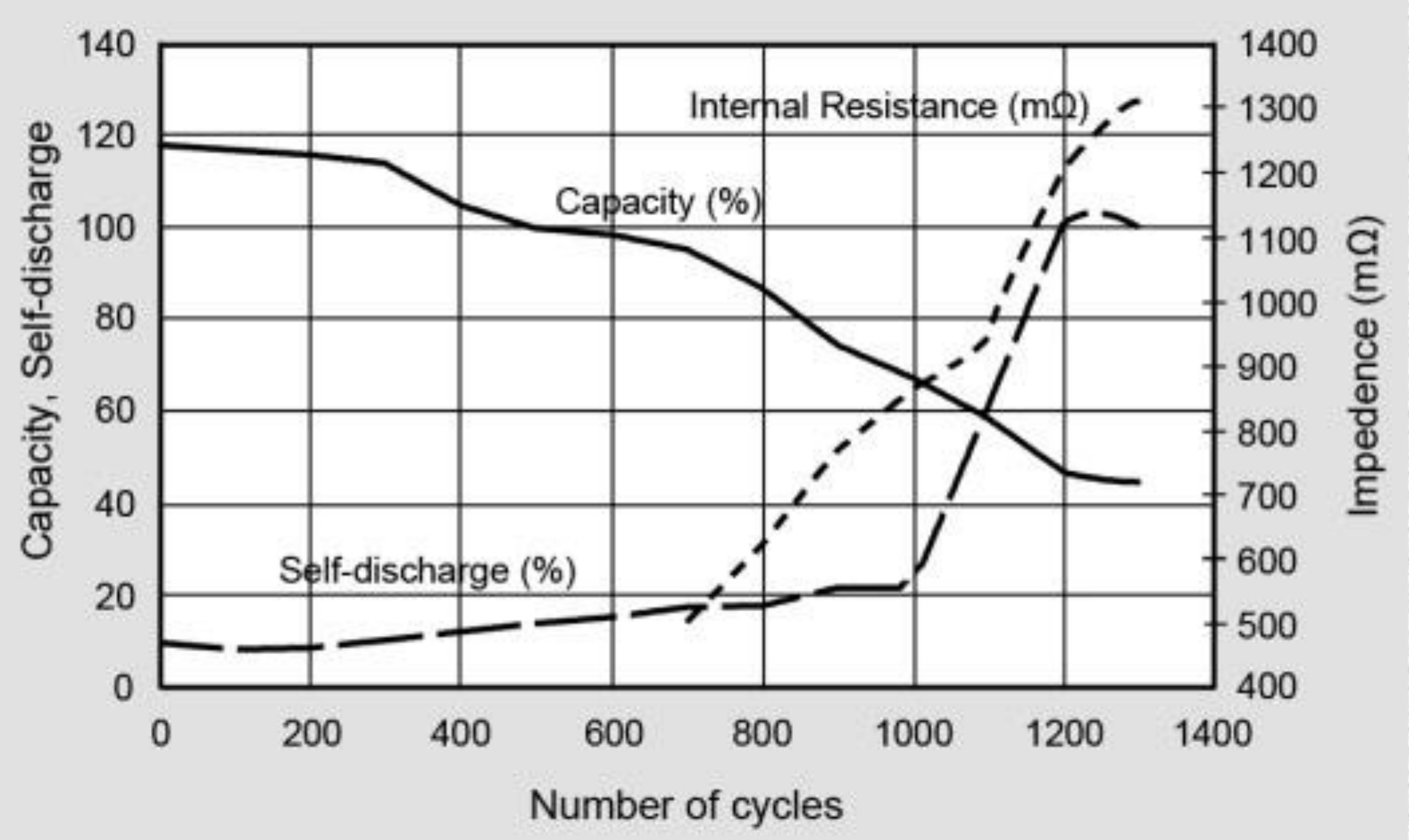
Lithium Ion Battery- *Cycle Life* Comparison

Stationary Battery Type:	Operating Voltage (per cell)	Specific Energy (Wh/Kg)	Operating Temperature	Cycle Life (to80% DOD)
Nickel Cadmium Pocket Plate	**1.2**	**40**	-40C to 50C (-40⁰F to 122⁰F)	>1500
Nickel Cadmium PBE	**1.2**	**60**	-20C to 50C (-4⁰F to 122⁰F)	>2000
VR Lead Acid (Pure lead grid)	**2.0**	**30-50**	-40C to 50C (-40⁰F to 122⁰F)	>500
VR Lead Acid (Ca)	**2.0**	**30-50**	30C to 50C* (-22⁰F to 122⁰F)	>300
Flooded Lead Acid (Ca)	**2.0**	**30-50**	0C to 49C (32⁰F to 120⁰F)	<100
Flooded Lead Selenium	**2.0**	**33 - 42**	-20C to 55C (-4⁰F to 131⁰F)	800 - 1000
LTIO (NMC cathode, LiTO anode)	**2.3**	**60 - 110**	0C to 40C (32⁰F to 104⁰F) (average over 24hr period 41-95⁰F)	>10000
Super Lithium Iron Phosphate (SLFP / LiFePO4 +NCA)	**3.7**	**90-120**	-40C to 50C (-40⁰F to 122⁰F)	7000
Lithium Iron Phoshpate (LFP/LiFePO4)	**3.2**	**90 - 110**	-20C to 60C (-4⁰F to 122⁰F)	>2000
Lithium Nickel Cobalt Al (NCA)	**3.6**	**2.1 kWhr**	-40C to 75C (-40⁰F to 167⁰F)	4300

We took the same chart from the previous slide, but reproduced it based on the stationary power applications. Again, the source used were averages from OEM manuals.

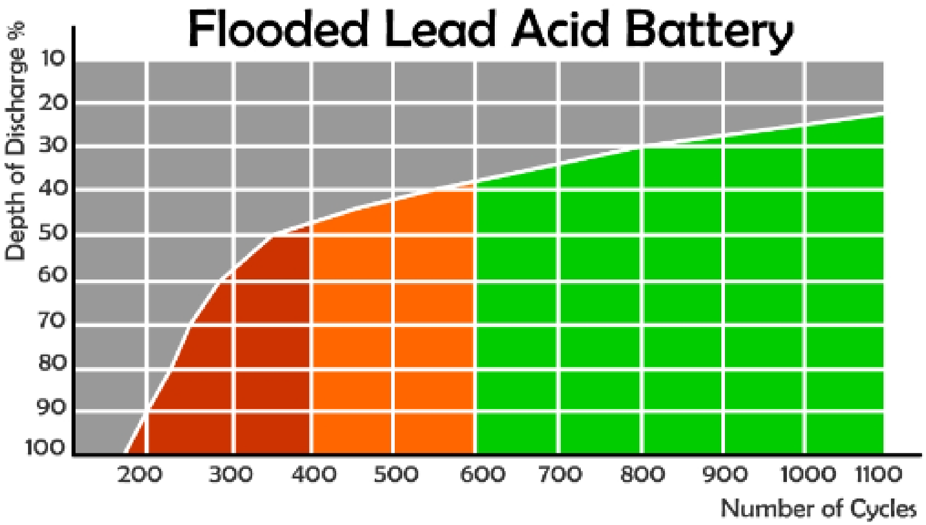
- VRLA Batteries must not be charged above 90 deg F, or below 32 deg F.

Cycle Life- Nickel Cadmium Pocket Plate

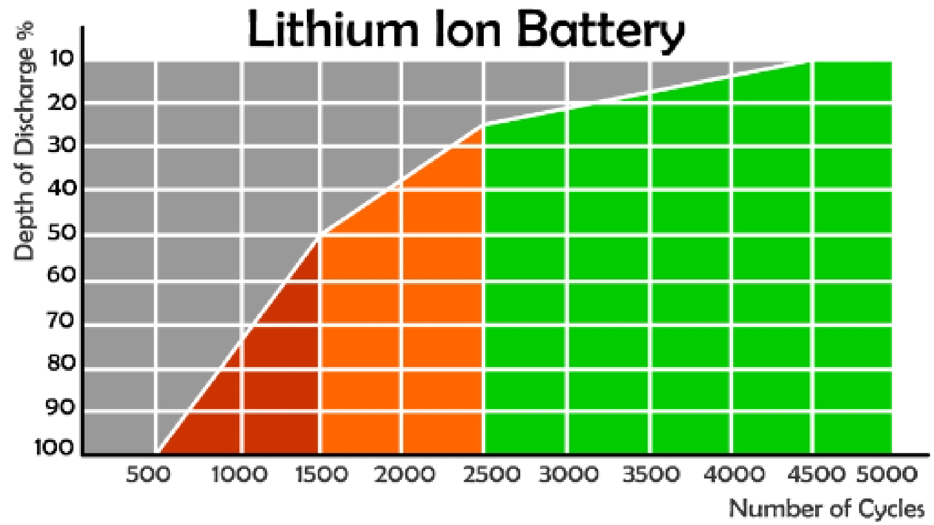


Lead Acid Grid Alloys- Cycle Life

The effects of Depth of Discharge on the cycle life of a battery



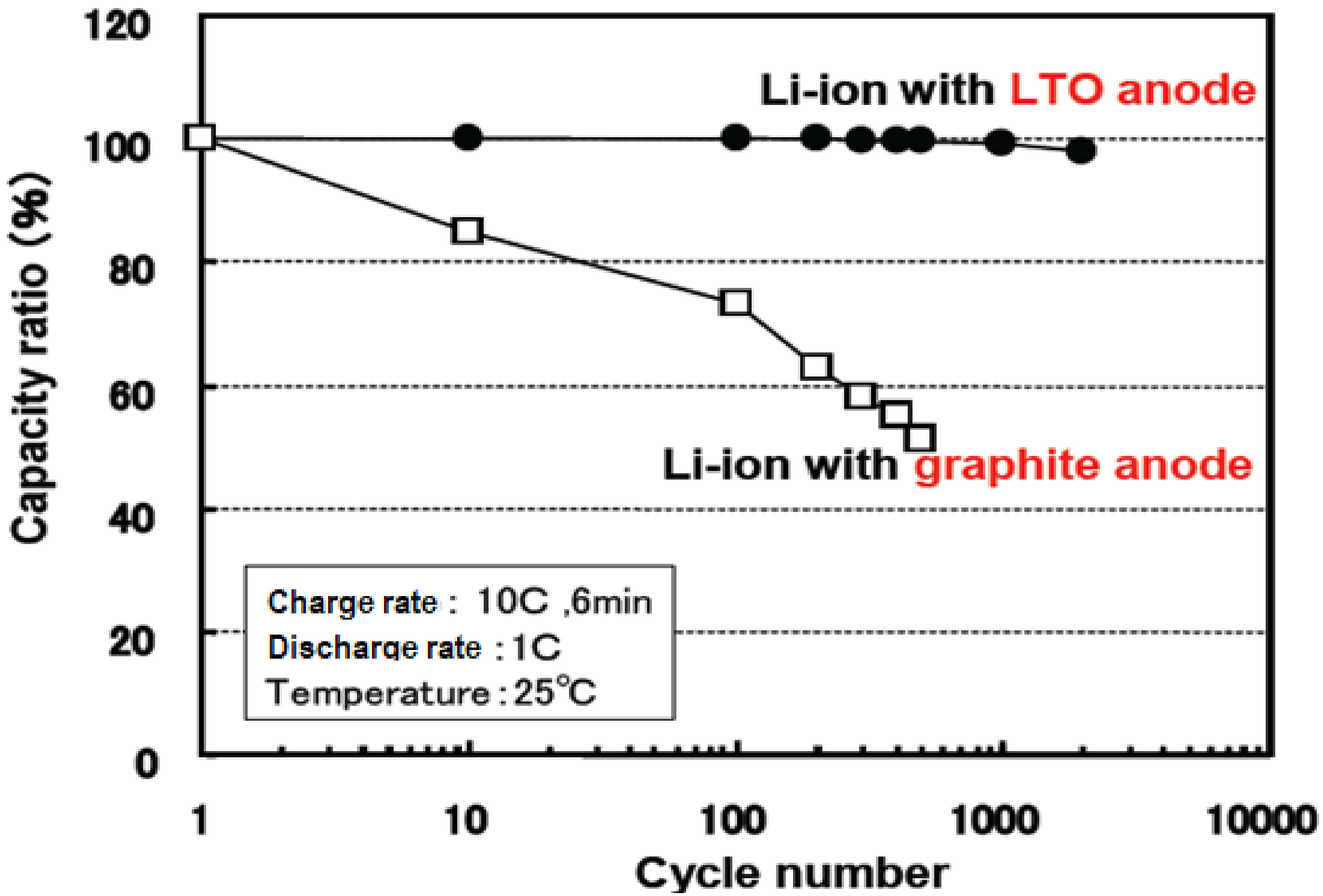
Depth of Discharge	Discharge Cycles
100% DoD	<150
50% DoD	350-450
25% DoD	900-1000
10% DoD	>1000



Depth of Discharge	Discharge Cycles
100% DoD	300-500
50% DoD	1200-1500
25% DoD	2000-2500
10% DoD	3750-4700

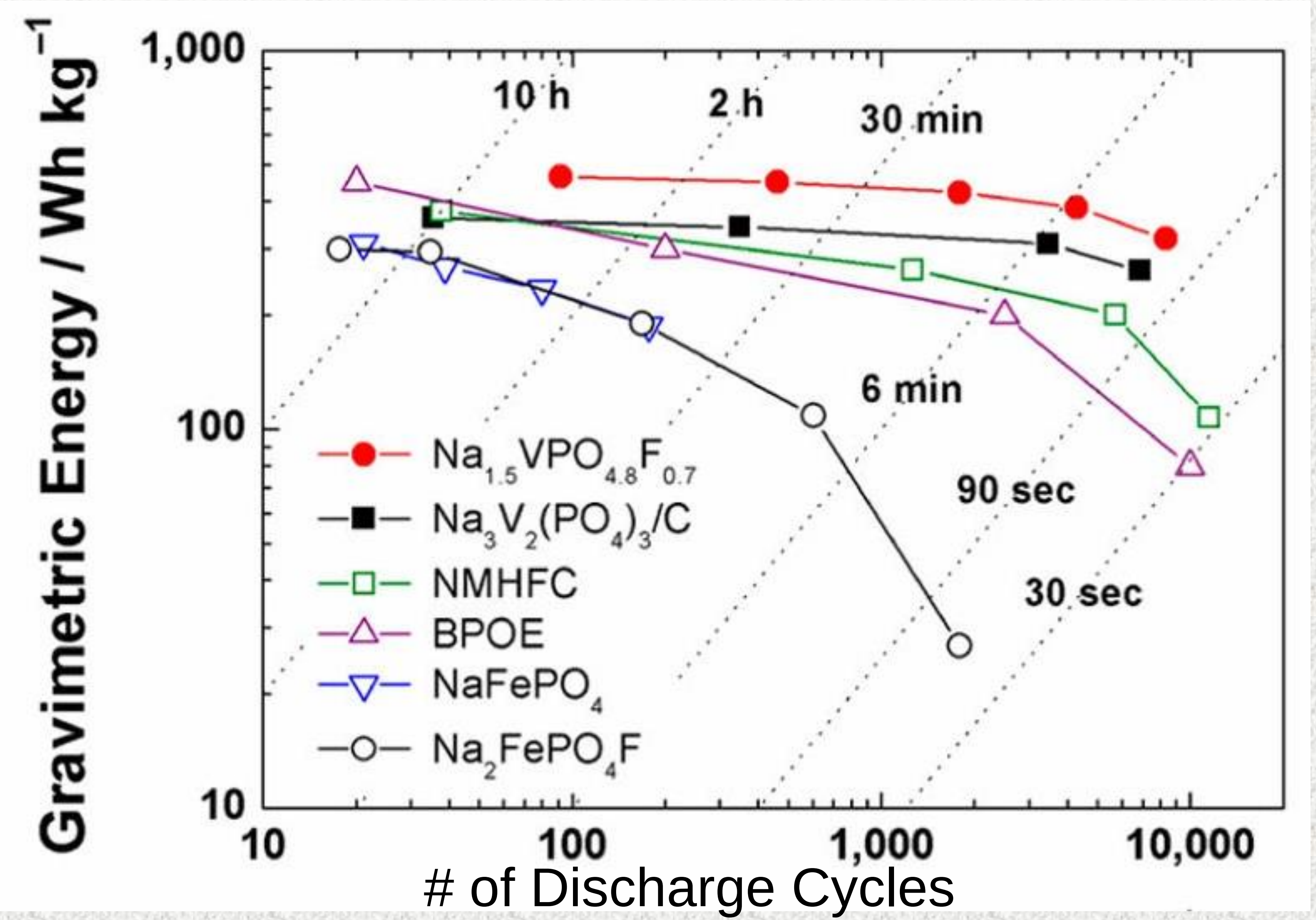
greensarawak.com

▪ LITHIUM ION BATTERY – Cycle Life



Lithium Technology offers superior cycle life .

SODIUM ION BATTERY – Cycle Life



Sizing Guidelines	Lead Acid	Nickel Cadmium	Lithium Ion
IEEE Sizing (Standby, station power, and UPS)	**IEEE 485**	**IEEE 1115**	**None Available**
NFPA Sizing (Engine Starting Emergency Gensets Centrifugal Fire Pumps)	**NFPA99** **NFPA110** **NFPA20**	**NFPA99** **NFPA110** **NFPA20**	**NFPA99** **NFPA110** **NFPA20**
Maintenance & Test Guidelines	**IEEE 450 (flooded)** **IEEE 1188 (VRLA)**	**IEEE 1106**	**IEEE 2030.2.1 (NERC PRC-005-2) (BESS)**
Fire Protection	**NFPA 52.3.2.7-8** **NFPA 850 Chapter 4**	**NFPA 52.3.2.7-8** **NFPA 850 Chapter 4**	**NFPA 52.3.2.7-8** **NFPA 850 Chapter 4**

Design Guidelines	BATTERY	CHARGER	INVERTER
Station Power	NFPA1 Chapter 52 IFC 608 IEEE 450	IFC 1206.2.10.4 UL 1564 NEMA PE 5	IFC 1206.2.10.5 UL 1741
UPS	NFPA 1 Chapter 52	NEMA PE 5	UL 1778 AS 562040.1.1
BESS	NFPA 855 UL 1774 (Repurpose)	IEEE 1106	IEEE 2030.2.1 (NERC PRC-005-2) (BESS)

NFPA 1 Chapter 12

FIRE SUPPRESSION FOR LITHIUM BATTERY SYSTEMS

Suppression:	Fire suppression system can consist of neutral gas extinguishers (for example Argonite, Nitrogen, Novec 1230, etc.,) or water sprinklers. • 2015 editions did not explicitly require suppression • 2018 required for all battery spaced w/ exceptions for telecommunication installations
Gas Detection	• Alarming for 25% of the lower flammability level of gas, as well as 50% of the IDLH (immediately dangerous to life or health) for toxic or highly toxic gases. • Must have visible and audible alarms in the battery room • Approved transmission to specific location • De-energizing of the battery rectified • Activation of the ventilation

Lithium Ion Battery- ***Operating Temperatures*** Comparison

Stationary Battery Type:	Operating Voltage (per cell)	Specific Energy (Wh/Kg)	Operating Temperature	Cycle Life (to80% DOD)
Nickel Cadmium Pocket Plate	**1.2**	**40**	-40C to 50C (-40^{0}F to 122^{0}F)	>1500
Nickel Cadmium PBE	**1.2**	**60**	-20C to 50C (-4^{0}F to 122^{0}F)	>2000
VR Lead Acid (Pure lead grid)	**2.0**	**30-50**	-40C to 50C (-40^{0}F to 122^{0}F)	>500
VR Lead Acid (Ca)	**2.0**	**30-50**	30C to 50C* (-22^{0}F to 122^{0}F)	>300
Flooded Lead Acid (Ca)	**2.0**	**30-50**	0C to 49C (32^{0}F to 120^{0}F)	<100
Flooded Lead Selenium	**2.0**	**33 - 42**	-20C to 55C (-4^{0}F to 131^{0}F)	800 - 1000
LTO (NMC cathode, LiTO anode)	**2.3**	**60 - 110**	0C to 40C (32^{0}F to 104^{0}F) (average over 24hr period 41-95^{0}F)	>10000
SLFP+NCA	**3.7**	**90-120**	-40C to 50C (-40^{0}F to 122^{0}F)	7000
LFP Lithium Iron Phoshpate (LiFePO4)	**3.2**	**90 - 110**	-20C to 60C (-4^{0}F to 122^{0}F)	>2000
NCA (Lithium Nickel Cobalt Al Oxide) (LiNiCoAlO2	**3.6**	**200-260**	-40C to 75C (-40^{0}F to 167^{0}F)	4300

We took the same chart from the previous slide, but reproduced it based on the stationary power applications. Again, the source used were averages from OEM manuals.

- VRLA Batteries must not be charged above 90 deg F. or below 32 deg F.

Lithium Ion Battery- ***Specific Energy*** **Comparison**

Stationary Battery Type:	**Operating Voltage** (per cell)	**Specific Energy** (Wh/Kg)	**Operating Temperature**	**Cycle Life (to80% DOD)**
Nickel Cadmium Pocket Plate	**1.2**	**40**	-40C to 50C (-40^{0}F to 122^{0}F)	>1500
Nickel Cadmium PBE	**1.2**	**60**	-20C to 50C (-4^{0}F to 122^{0}F)	>2000
VR Lead Acid (Pure lead grid)	**2.0**	**30-50**	-40C to 50C (-40^{0}F to 122^{0}F)	>500
VR Lead Acid (Ca)	**2.0**	**30-50**	30C to 50C* (-22^{0}F to 122^{0}F)	>300
Flooded Lead Acid (Ca)	**2.0**	**30-50**	0C to 49C (32^{0}F to 120^{0}F)	<100
Flooded Lead Selenium	**2.0**	**33 - 42**	-20C to 55C (-4^{0}F to 131^{0}F)	800 - 1000
LTIO (NMC cathode, LiTO anode)	**2.3**	**60 - 110**	0C to 40C (32^{0}F to 104^{0}F) (average over 24hr period 41-95^{0}F)	>10000
Super Lithium Iron Phosphate (LFP / LiFePO4 +NCA)	**3.7**	**90-120**	-40C to 50C (-40^{0}F to 122^{0}F)	7000
LFP Lithium Iron Phospate (LFP/LiFePO4)	**3.2**	**90 - 110**	-20C to 60C (-4^{0}F to 122^{0}F)	>2000
Lithium Nickel Cobalt Al (LiNiCoAlO2/NCA)	**3.6**	**200-260**	-40C to 75C (-40^{0}F to 167^{0}F)	4300

We took the same chart from the previous slide, but reproduced it based on the stationary power applications. Again, the source used were averages from OEM manuals.

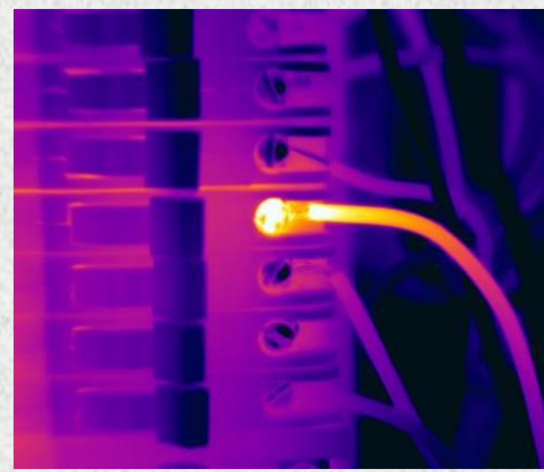
Lithium Ion Battery- *Storage Comparison*

Stationary Battery Type:	Self Discharge Rate	Shelf Life	Storage Temperature
Nickel Cadmium Pocket Plate	1.2	5 Years	-40C to 50C (-40⁰F to 122⁰F)
Nickel Cadmium PBE	1.2	2 Years	-20C to 50C (-4⁰F to 122⁰F)
VR Lead Acid (Pure lead)	2.0	2 Years	-40C to 50C (-40⁰F to 122⁰F)
VR Lead Acid (Ca)*	2.0	6-Mo*	30C to 50C* (-22⁰F to 122⁰F)
Flooded Lead Acid (Ca)	2.0	1 Year	0C to 49C (32⁰F to 120⁰F)
Flooded Lead Selenium	2.0	1 Year	-20C to 55C (-4⁰F to 131⁰F)
LTIO (NMC cathode, LiTO anode)	2.3	15 Year	0C to 40C (32⁰F to 104⁰F) (average over 24hr period 41-95⁰F)
LFP+NCA	3.7	12-15	-40C to 50C (-40⁰F to 122⁰F)
Lithium Iron Phoshpate (LFP/LiFePO4)	3.2	N/A	-20C to 60C (-4⁰F to 122⁰F)
Lithium Nickel Cobalt Al(NCA) (LiNiCoAlO2/NCA)	3.4	10 -20	-40C to 75C (-40⁰F to 167⁰F)

Maintenance Requirements: IEEE 2030.2.1 (BESS)

- **Vacuum/ Clean cells/cabinet**
- **Check/Adjust torque**
- **Download data from BMS**
- **Thermal scan connections and cells**
- **Flash calibration/firmware if required**

Must meet UL 1642.5 for technician replaceable modules.



Source: **IEEE 2030.2.1**

▪ LITHIUM BATTERY TRAINING- Best Practice Standards

2021 IFC CHAPTER	SUBJECT (CHANGES)
7	Fire and smoke protection features
8	Interior finish, decoration materials and furnishings
9	Fire protective and life safety systems
10	Means of egress
12	Energy Systems (1206.2 Stationary Storage Battery Systems)
33	Fire safety during construction and demolition

BATTERY ROOM DESIGN- IEEE and NFPA Guidelines

Battery Room Considerations:	Lithium Ion
Charger/s *	Single only
Spill containment	**N/A**
Spill Neutralization (5.0-7.0 PH)	**N/A**
PPE	Yes (Electrical)
Eyewash station (15 min flush Minimum)	**N/A**
Gas Detection & Alarm	YES
Ventilation	**N/A**
Safety Signage	Yes
Battery Disconnect	Yes
Battery cabling	Special
Access/Egress	**Yes/ Location Dependent**
Fire Suppression * 2018 NFPA 52.3.2.7-8	**Yes**
Fire Protective Clearances * 2018 NFPA 52.3.2.7-8	**Yes**


Eyewash


H2 Monitor

PPE


Spill barriers


Spill Response

Signage

BATTERY TECHNOLOGY – CODES AND REGULATIONS

IFC 608.1 (prior 2018)	Flooded Lead Acid	Flooded Nickel Cadmium	Valve Regulated Lead Acid	Lithium Ion	Lithium Metal Cells
Safety caps	Venting Caps (608.2.1)	Venting Caps (608.2.1)	Self sealing flame arresting caps (608.2.2)	**N/A**	**N/A**
Thermal Runaway Management	**N/R**	**N/R**	Required (608.3)	**N/R**	Required (608.3)
Spill Control	Required (608.5)	Required (608.5)	**N/R**	**N/R**	**N/R**
Neutralization	Required (608.5.1)	Required (608.5.1)	Required (608.5.2)	**N/R**	**N/R**
Ventilation	Required (608.6.1 and 6.08.6.2)	Required (608.6.1 and 6.08.6.2)	Required (608.6.1 and 6.08.6.2)	**N/R**	**N/R**
Signage	Required (608.7)	Required (608.7)	Required (608.7)	Required (608.7)	Required (608.7)
Seismic Protection	Required (608.8)	Required (608.8)	Required (608.8)	Required (608.8)	Required (608.8)
Smoke Detection	Required (608.9)	Required (608.9)	Required (608.9)	Required (608.9)	Required (608.9)

BATTERY TECHNOLOGY – Lithium Battery Room Requirements

ADDITIONAL RESTRICTIONS FOR LION BATTERIES)

1. Must have means of disconnect from charging source on overtemp.
2. Must be installed below 75 feet from ground level.
3. Must be installed higher than 30 feet below ground. 506.4 and 506.5
4. **High Hazard Classification required for exceeding MAQ.**
5. Separation of 36” between **arrays** of batteries and/or other equipment that is not 1-hour fire rated. Array for battery is defined by NFPA855 as 20kWhrs of battery for lithium ion technologies.
6. Additional permitting requirements for operation as well as location within the interior of a building.
   Section 506.4, 506.5, 508.2.3, 508.3.2, 508.4.2

BATTERY TECHNOLOGY – Lithium Battery Room Requirements

NMC Lithium Fires are well publicized on the internet:

Jecheon, S Korea

APS in Arizona

Disconnection from power source is **<u>not</u>** enough to stop thermal runaway.

How Safe are these LION systems:

Monitoring makes the difference.

- **Each cell is monitored for:**
  Voltage,
  Temperature,
  Current.

- **Each string is monitored for:**
  Reverse Polarity Protection,
  Impedance,
  Voltage,
  Temperature,
  Current.

Controls provide additional safety.

- **Hardened electronics/PLC**
- **Thermal Runaway Control (55°C alarm/ 65°C disconnect)**
- **Cell Balancing**
- **CANBUS for Local and Remote Communication**
- **Each cell and string has the ability to be removed from the DC bus without impacting operation of the others (cell-level disconnecting means)**

▪ LITHIUM ION - *BATTERY CABINETS*

- NEMA 1, 3R, 4X CABINETS
- **TOP ENTRY**
- **HINGED FRONT DOOR**
- **SEISMIC / NON-SEISMIC**

Cabinetized Systems:

Cabinetry	▪ Typically 90” (2286 mm) Height
	▪ Multi-string cabinet (offers redundancy) ▪ Single String cabinet (no redundancy) ▪ Disconnect per string ▪ Disconnect per cabinet ▪ Seismic rated per IFC 1206.2.4
	Components: ▪ Battery monitoring/alarm notification system ▪ Battery management system ▪ System communication module ▪ Battery modules ▪ Battery DC disconnect
	▪ NEMA1 (IP20), NEMA3R (IP54) or Higher
Electronics	▪ Hardened electronics
	▪ Redundant monitoring (Not typical. Most manufacturers operate without the communications interface.)

Lithium ION Battery Technology- *Safety Concerns*

Predominant Safety Concerns:	Remedy within the system:
Over-temperature	Cell, module, and string level protection
Over-Voltage	String level DC Disconnect, but still able to charge
Over-Discharge	Module level disconnect from load at 2.5 vpc, but continues to charge
Thermal Runaway	**Alarm at 55^0 C, Charge termination at 70^{0}C**
Moisture Intrusion	Humidity and moisture control
Cell Rupture (physical)	Containment within the module
Fire Propagation / Containment	Fire Suppression. Notification, clearances, testing per UL9540A and **UL9540**, Noncombustible Cabinets IFC 608
Communication Failure	Redundant real time communication modules, if N+1
Remote Comm Failure	Does not affect the module and inter-string communications.
Battery Management System Failure	Autonomy, optional redundancy in BMS
Charge Control Failure	Disconnection at the string level, module level and system level

Lithium ION Battery Technology- BMS *SAFETY*

CERTIFICATION	Description
UL 9540; Article 706 of NFPA 70, (Also 9540A)	* Environmental Tests, Electrical Tests, Mechanical Tests, and 9540A for test methods for Thermal Runaway Fire Propagation.
UL 1973	Materials, Enclosures, Safety Analysis, Safety Controls, Bonding, Insulation, Spacings, Grounding…Fire Test
IEC 61508	Functional safety of electrical/electronic / Programmable electronic safety-related systems
IEC 62040-1	Uninterruptible Power Systems (UPS) Safety Requirements
IEC 62040-2	Uninterruptible Power Systems (UPS) Electromagnetic Compatibility Requirements
IEC 62040-3	Uninterruptible Power Systems (UPS) Environmental Aspects
IEEE P2686	Recommended Practice for Battery Management Systems in Energy Storage Applications
FCC 47 CFR Part 15 Subpart B Class A	FCC EMC Conformity (Unintentional Radiators)
FM DS 5-33	Recommendations for construction, location, fire protection, electrical system protection and design of LIB ESS

Lithium ION Battery Technology- *Cabinetized Systems*

How Safe are these LION systems:

Cabinetry

Each **cell** has the ability to be removed from the DC bus without impacting operation of the others (cell-level disconnecting means)

Cell level safety testing to **UL1642, 1973, 9540**

Each **cell** is protected from:

- Overcurrent
- Over-voltage
- Over-temperature

Each **cell** is monitored for:

- Impedance,
- Voltage,
- Temperature,
- Current.

Enables cell "balancing".

- Each **module** has overcurrent protection and microprocessor controlled monitoring **UL 1973**
- **Noncombustible cabinet/ enclosure IFC 608.4.2**
- **NEMA3R (IP54) or Higher**

Electronics

- **Hardened electronics for control, supervisory and monitoring UL 1998 and IEC 61000-6-2**
- **Redundant supervisory monitoring + dry contacts**

Lithium ION Battery Technology- *Shipping*

Shipping Requirements:

- **Each cell / module must ship in its own carton (Shipped loose for field installation)**
- **Replacement Cells are carrier specific for shipping and handling**
- **UN classification (spent) ship as Class 9**
- **Requires 3-6 months for air cargo approval**
- **CDL Hazmat licensed driver required for transport**
- **Certified to UN/DOT 38.3**

Packing per 49 CFR 173.185:	Lithium Ion Battery	Lithium Metal Battery
Stand Alone	(P.I. 965) UN 3480 Class 9 group 2	(P.I. 968) UN 3090
Packed w/ Eqt but not installed in equipment	(P.I. 966) UN 3481	(P.I. 969) UN 3091
Contained in Equipment	(P.I. 967) UN 3481	(P.I. 970) UN 3091

Chemistry

CHEMISTRY: ***(LITHIUM IRON PHOSPATE)*** $LiFePO_4$

2-Part Reaction:

$$LiFePO_4 \longleftrightarrow FePO_4 \leftarrow \text{Electrolyte} \rightarrow Li + e^- + C \longleftrightarrow LiC_5$$

Cathode (+ electrode)
Aluminum Current Collector

Anode (- electrode)
Copper Current Collector

Ethylene Carbonate (EC)
/Dimethylcarbonate (DMC)

$\longrightarrow$ ***Left to right is Charging.***

$\longleftarrow$ ***Right to Left is Discharging.***

Larger ***voltage per cell*** means fewer cells required for the same output power.

CELL VOLTAGE:

3.4 VDC per cell

CHEMISTRY: ***(LITHIUM IRON PHOSPATE)*** $LiFePO_4$

2-Part Reaction:

$$LiFePO_4 \longleftrightarrow FePO_4 \leftarrow \text{Electrolyte} \rightarrow Li + e^- + C \longleftrightarrow LiC_5$$

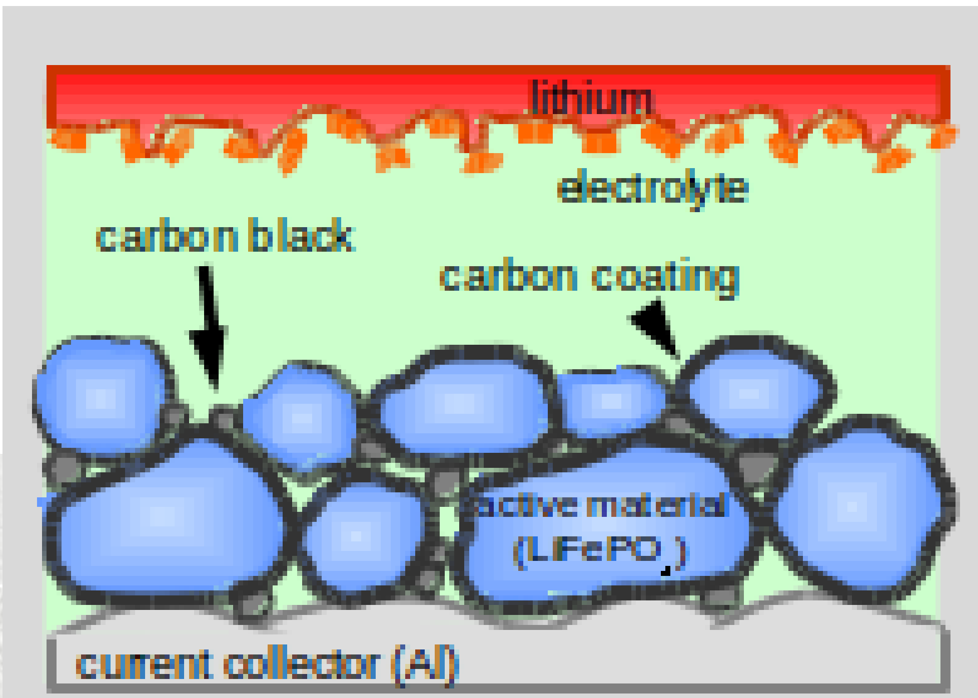
Cathode (+ electrode)

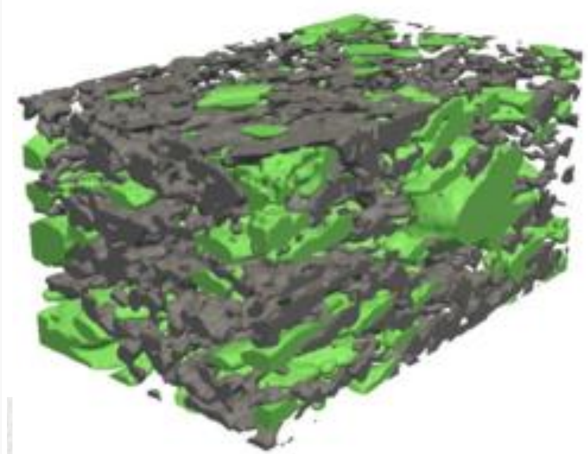
Ethylene Carbonate (EC)
/Dimethylcarbonate (DMC)

Anode (- electrode)

Left to right is Charging.
Right to Left is Discharging.

Carbon





SEM Image
Black= carbon black
Green= Lithium Iron Phosphate

Chemistry

CHEMISTRY: ***(LITHIUM IRON PHOSPATE)*** $LiFePO_4$

2-Part Reaction:

$$LiFePO_4 \longleftrightarrow FePO_4 \leftarrow \text{Electrolyte} \rightarrow Li + e^- + C \longleftrightarrow LiC_5$$

Cathode (+ electrode) *Anode (- electrode)*

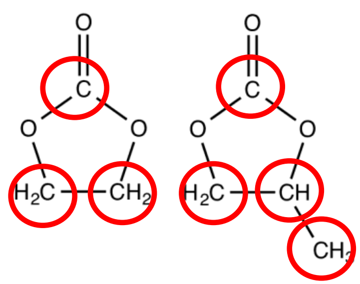
Ethylene Carbonate (EC)
/Dimethylcarbonate (DMC)

Left to right is Charging.
Right to Left is Discharging.

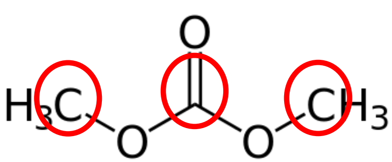
Carbon

Electrolyte:

Ethylene Carbonate:



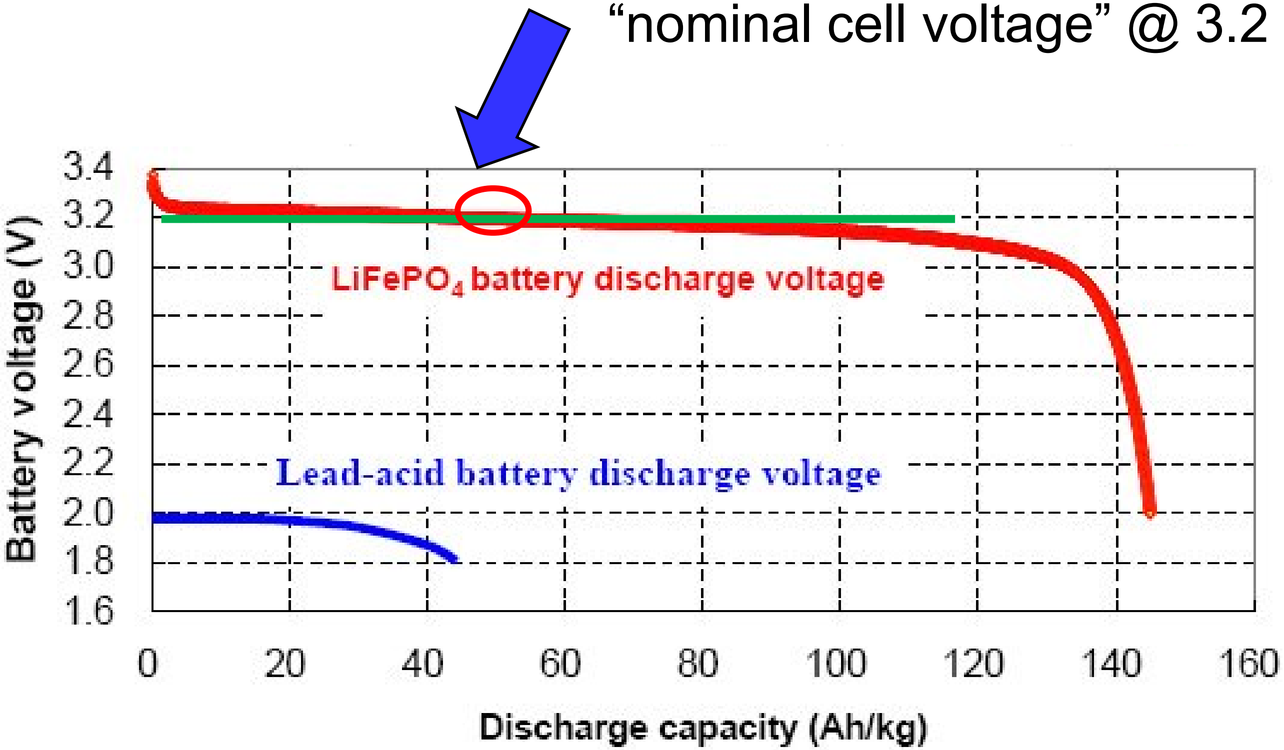
Dimethylcarbonate:



CHEMISTRY: (LITHIUM IRON PHOSPATE) $LiFePO_4$

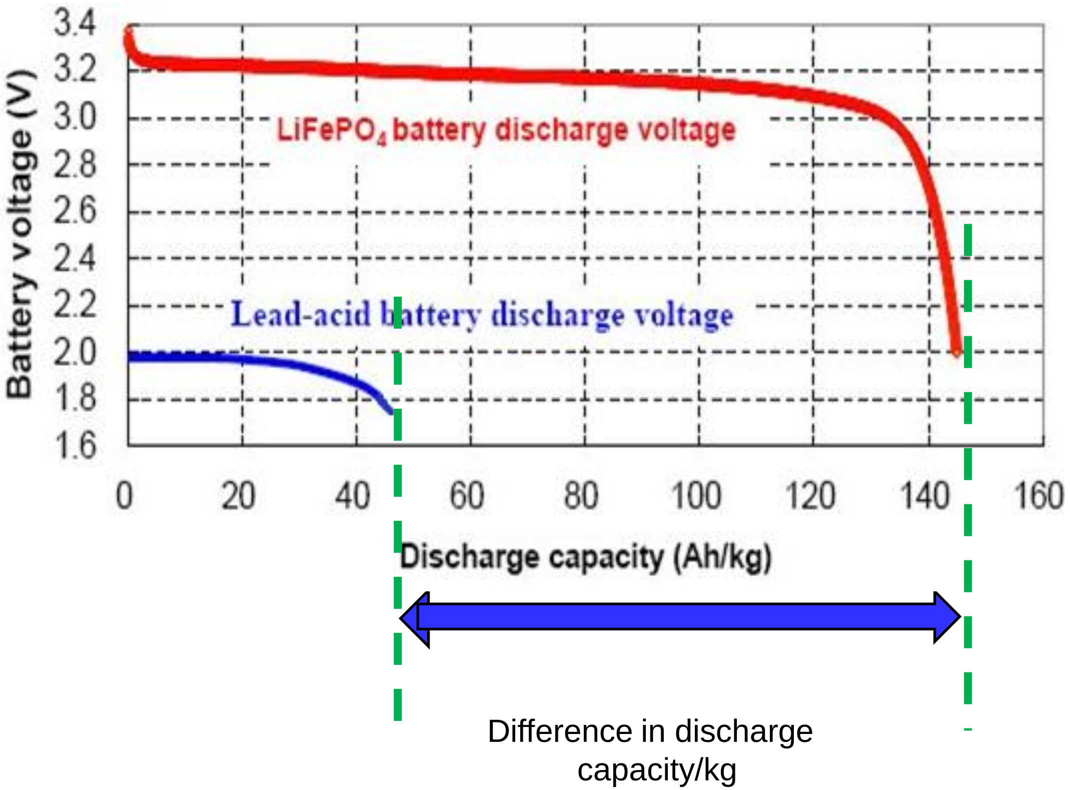
Nominal Voltage:

The average voltage is where the flat part of the curve intersects the green line. This is the "nominal cell voltage" @ 3.2 vpc.



▪ Chemistry

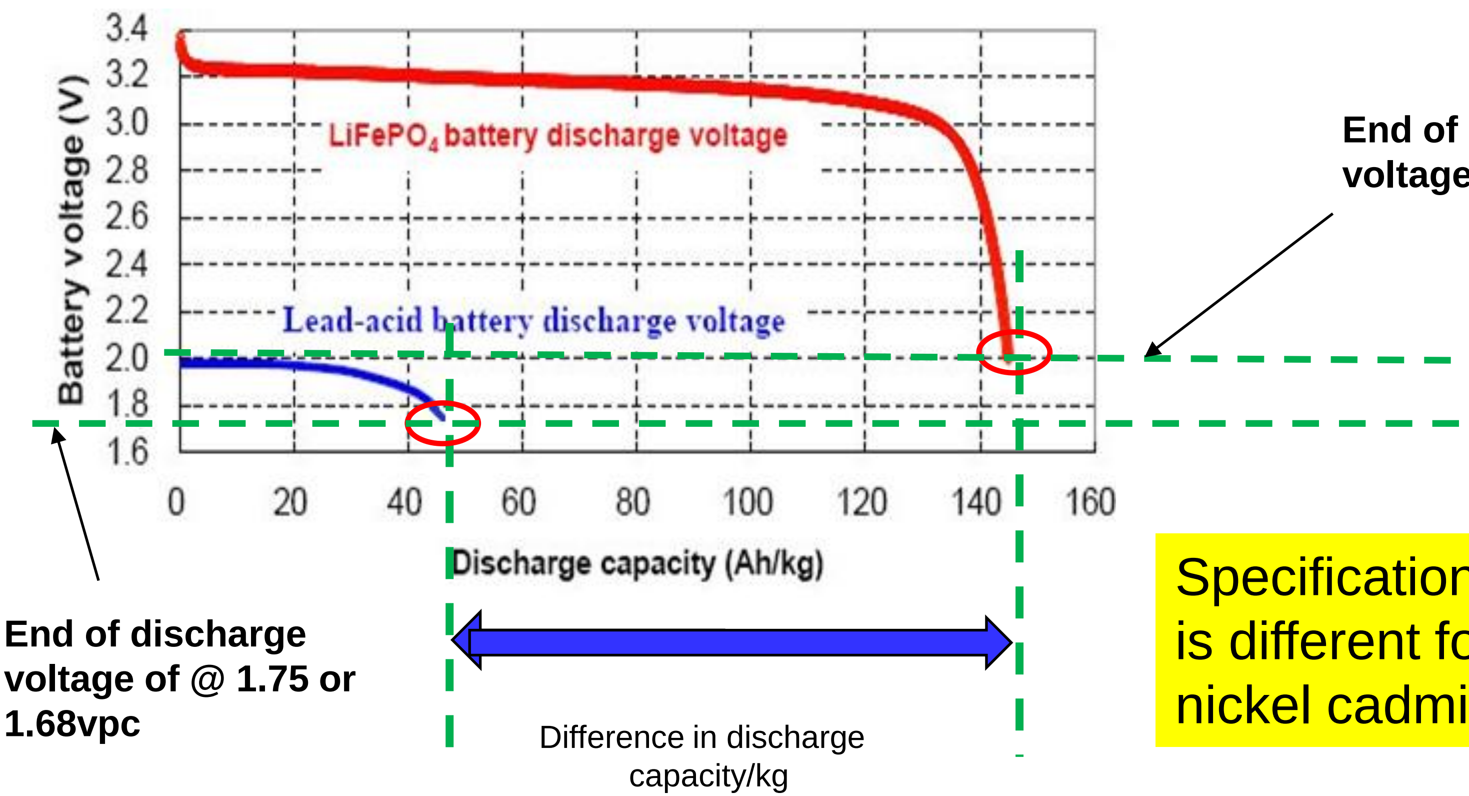
CHEMISTRY: ***(LITHIUM IRON PHOSPATE)*** $LiFePO_4$



The capacity per kilogram is nearly 3.5 times that of lead acid high rate batteries.

Chemistry

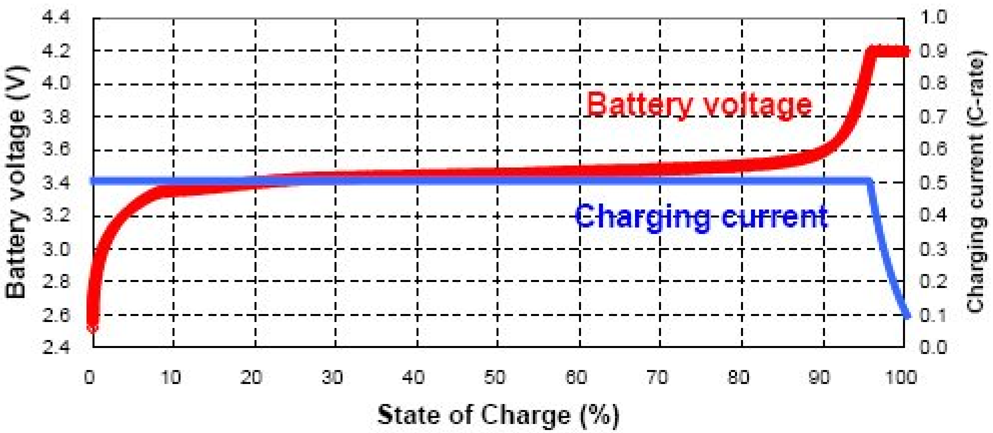
CHEMISTRY: ***(LITHIUM IRON PHOSPATE)*** $LiFePO_4$



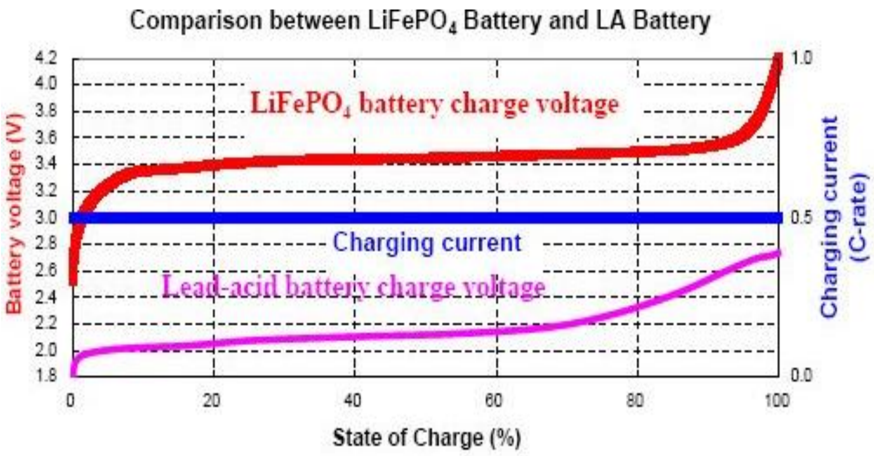
Specification limit for ***EODV*** is different for lead acid, nickel cadmium, and LION.

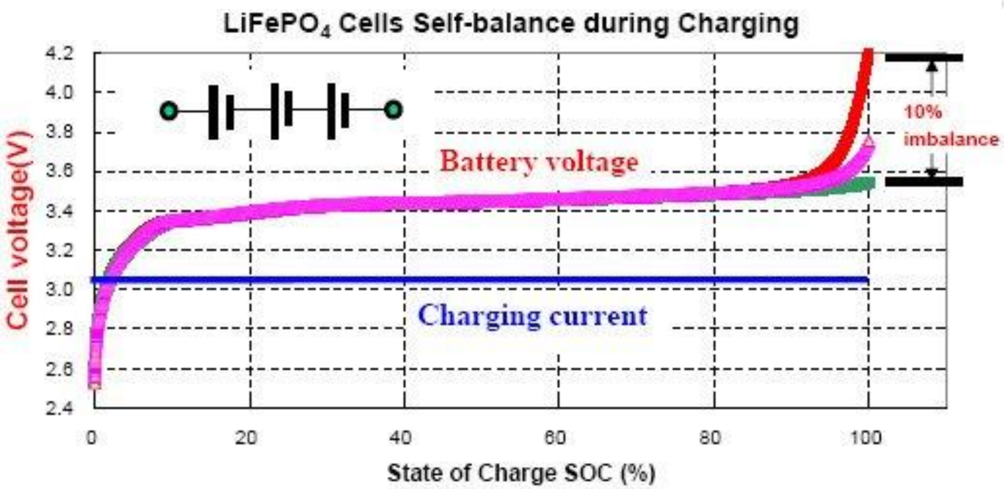
▪ Chemistry

CHEMISTRY: ***(LITHIUM IRON PHOSPATE)*** $LiFePO_4$



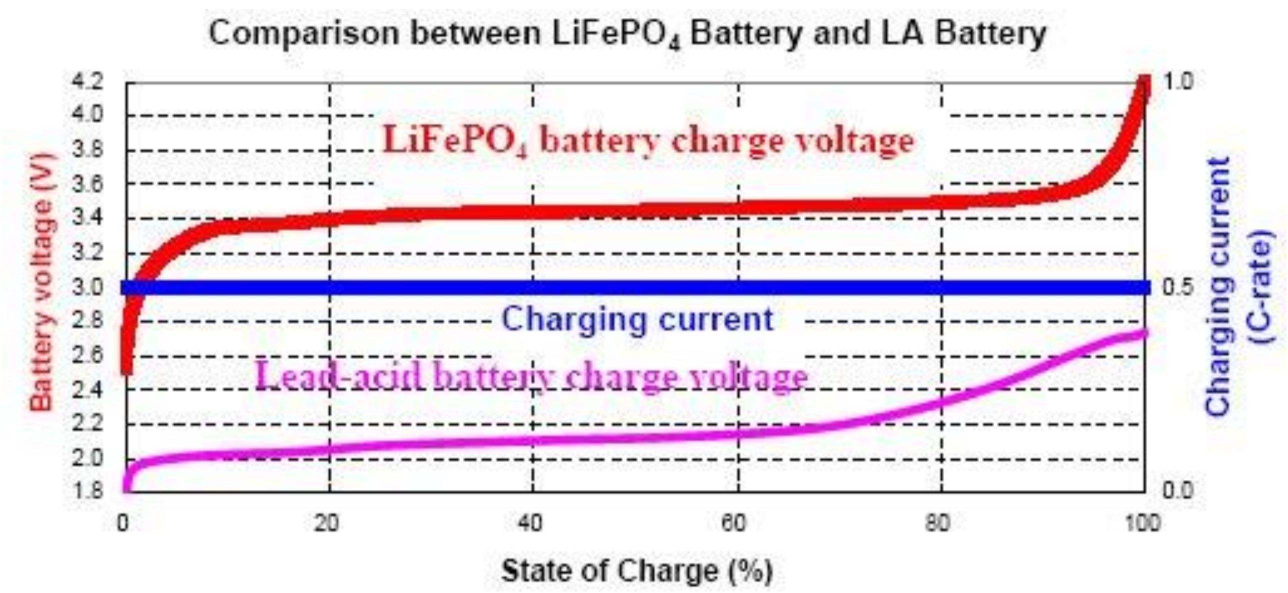
Overcharge tolerance is better on LiFePO4 than with LTO/LiCoO2





Chemistry

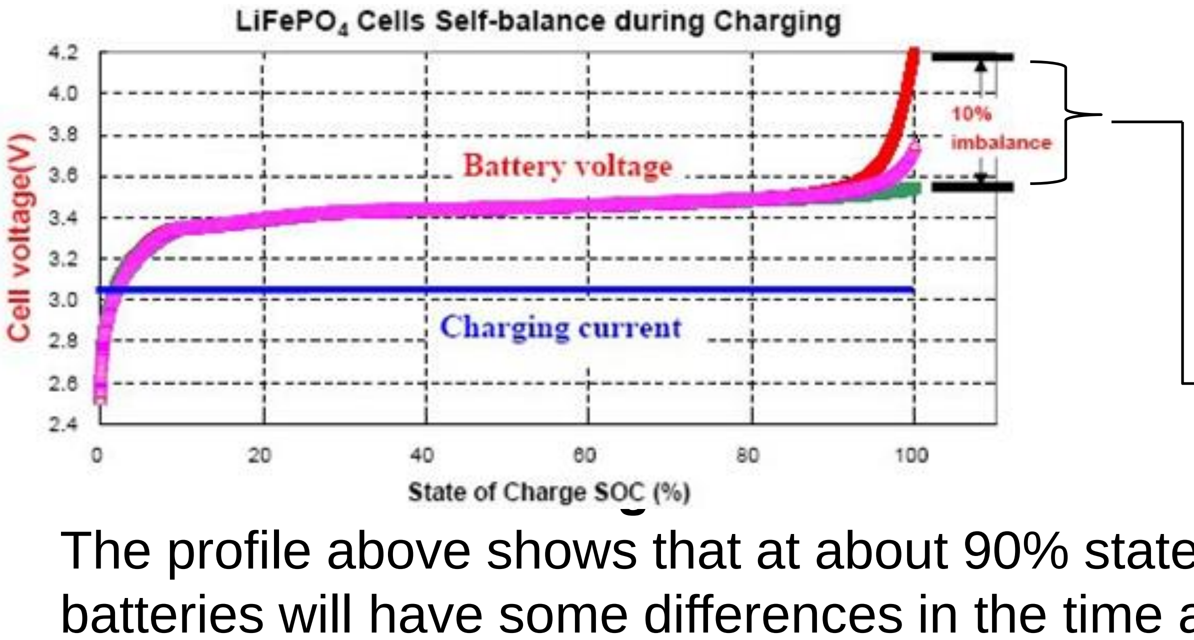
CHEMISTRY: (LITHIUM IRON PHOSPATE) $LiFePO_4$



Charging Voltage per cell is different than the lead acid batteries as you can see from the chart. The charging voltage of most chargers and UPS modules is adjustable. Care must be taken to ensure that the charging voltage of the equipment is taken into consideration for battery sizing purposes.

Chemistry

CHEMISTRY: ***(LITHIUM IRON PHOSPATE)*** $LiFePO_4$



The profile above shows that at about 90% state of charge, the batteries will have some differences in the time at which they reach the 100% state of charge.

Chemistry- LTO

CHEMISTRY: ***(LITHIUM TITANATE OXIDE ANODE)*** $Li_4Ti_5O_{12}$

Chemical Formula:

$$\mathbf{Li_4Ti_5O_{12} + 6LiCoO_2 \longleftrightarrow Li_7Ti_5O_{12} + 6Li_{0.5}CoO_2}$$

(Anode) (Cathode) (Anode) (Cathode)

Aluminum Current Collector ***Copper Current Collector***

Cell Potential: 2.1 VDC per cell

(patented)

Li = Lithium
Co = Cobalt
Ti = Titanium
O = Oxygen

$\rightarrow$ ***Left to right is Charging.***

$\leftarrow$ ***Right to Left is Discharging.***

Chemistry- *(LITHIUM TITANATE OXIDE ANODE)*

CHEMISTRY: ***(LITHIUM TITANATE OXIDE ANODE)*** $Li_4Ti_5O_{12}$

Chemical Formula:

$$Li_4Ti_5O_{12} + 6LiCoO_2 \longleftrightarrow Li_7Ti_5O_{12} + 6Li_{0.5}CoO_2$$

(Anode) (Cathode)

Cell Potential: **2.1** VDC per cell
(patented)

Li = Lithium
Co = Cobalt
Ti = Titanium
O = Oxygen

Noteworthy: Absence of Carbon

LITHIUM ION BATTERY – *SUMMARY*

BENEFITS:

Excellent benefits over single strings of VLA or NICAD

Excellent repetitive **Cycling**

Excellent high & low temperature operation

Rapid Recharge capability

Built-in **Charging Regulation**

Very **compact** and light weight for short duration discharges

Very **predictable** and stable life and cycle life

12-15 year "**Maintenance Free"** operation

Built-in **Thermal Runaway Control**

Cell and string level **Battery Monitoring (**standard)

Superior **Shelf Life**

LITHIUM ION BATTERY – *SUMMARY*

BEST APPLICATIONS:

Single String VLA or NICAD Replacement

Engine Generator Start

Switchgear/Process Control

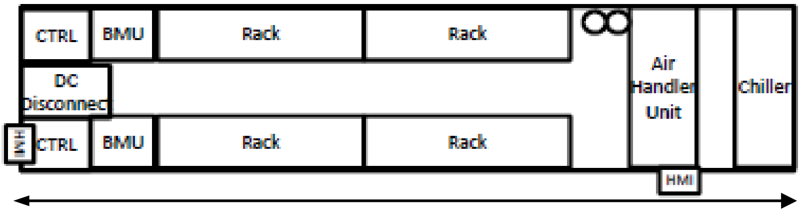
Wind Turbine Energy Storage

Photovoltaic System Energy Storage

<5 Minute UPS Applications

Flicker and Voltage Control Applications

LITHIUM ION BATTERY TRAINING- *LARGE BESS*



Max dimensions: 45' L x 8' D x 9.5' T

Controller Functions:
• Charge/discharge, Balancing control
• SOC Target Control
• Active/ Reactive Power Controls
• Protection and Abnormality Detection
• DC Contactor Control
• Cell Balancing Control

Container Components:
• Integrated HVAC system / liquid cooling system
• Standard outdoor-rated container
• Modifiable racks based on capacity requirements
• Built-in fire alarm/suppression system

PER NFPA 850 4.4.3.2: If 100' from buildings, lot lines, public ways, storage, then remote installations can omit water supply and fire suppression if AHJ agrees.

▪ LITHIUM ION BATTERY – *LARGE POWER*

- **LARGE POWER (BESS)**

  Super cycling and fast recharge

  No Building Code Compliance

  Excellent repetitive cycling

  Excellent high temperature operation

  Excellent low temperature operation

  Very compact and light weight

  Very predictable and stable life and cycle life

  12-15 year maintenance free operation

  Battery & cell monitoring is standard

Ideal:

PV

Wind

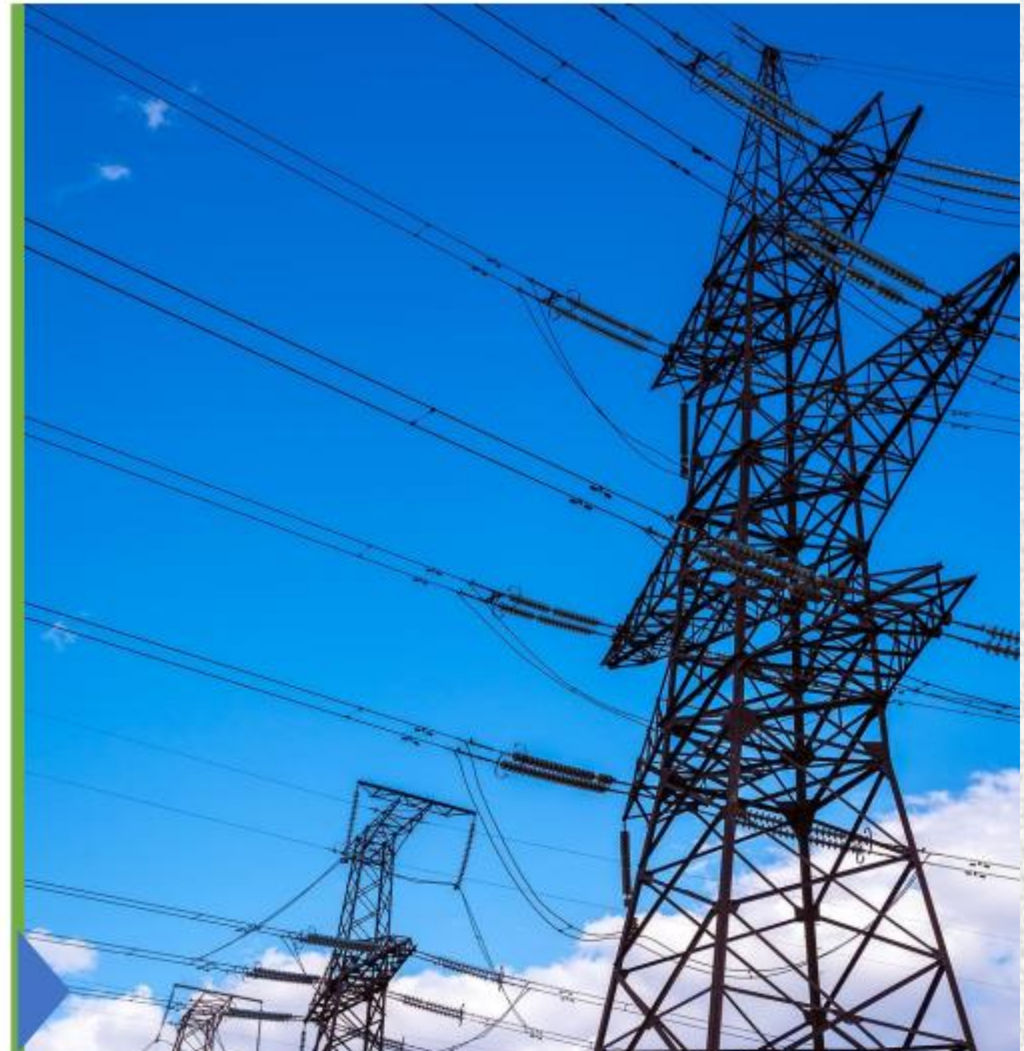
Regen

Standby

Transfer

UTILITY GRID INTETERCONNECTION REQUIRES COMPLIANCE:

UL 9540



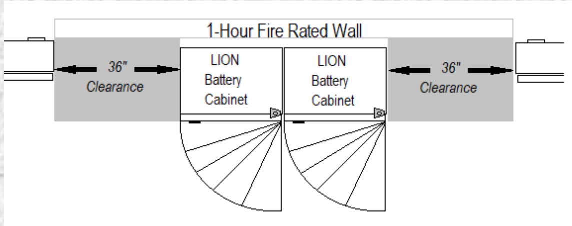
Utility Grid Interaction

- UL 1741 including its Supplement SA
  or
  The Standard for General Use Power Supplies, C22.2 No. 107.1, including:
  - IEEE 1547, 1547.1, 1547A, 1547.1A
  - NERC PRC-024-1 as applicable

LIMITATIONS:

- FM, NFPA and IEEE practices are lagging for Station Power.
- **Charging Compatibility** must be approved and/or certified by the manufacturer.
- External System DC breaker may be required for systems of 3+ cabinets for **EPO** capability with UPS.

- Manufacturers want **compatibility** for replacements.
- Maximum allowable quantities affects **Occupancy Classifications.**



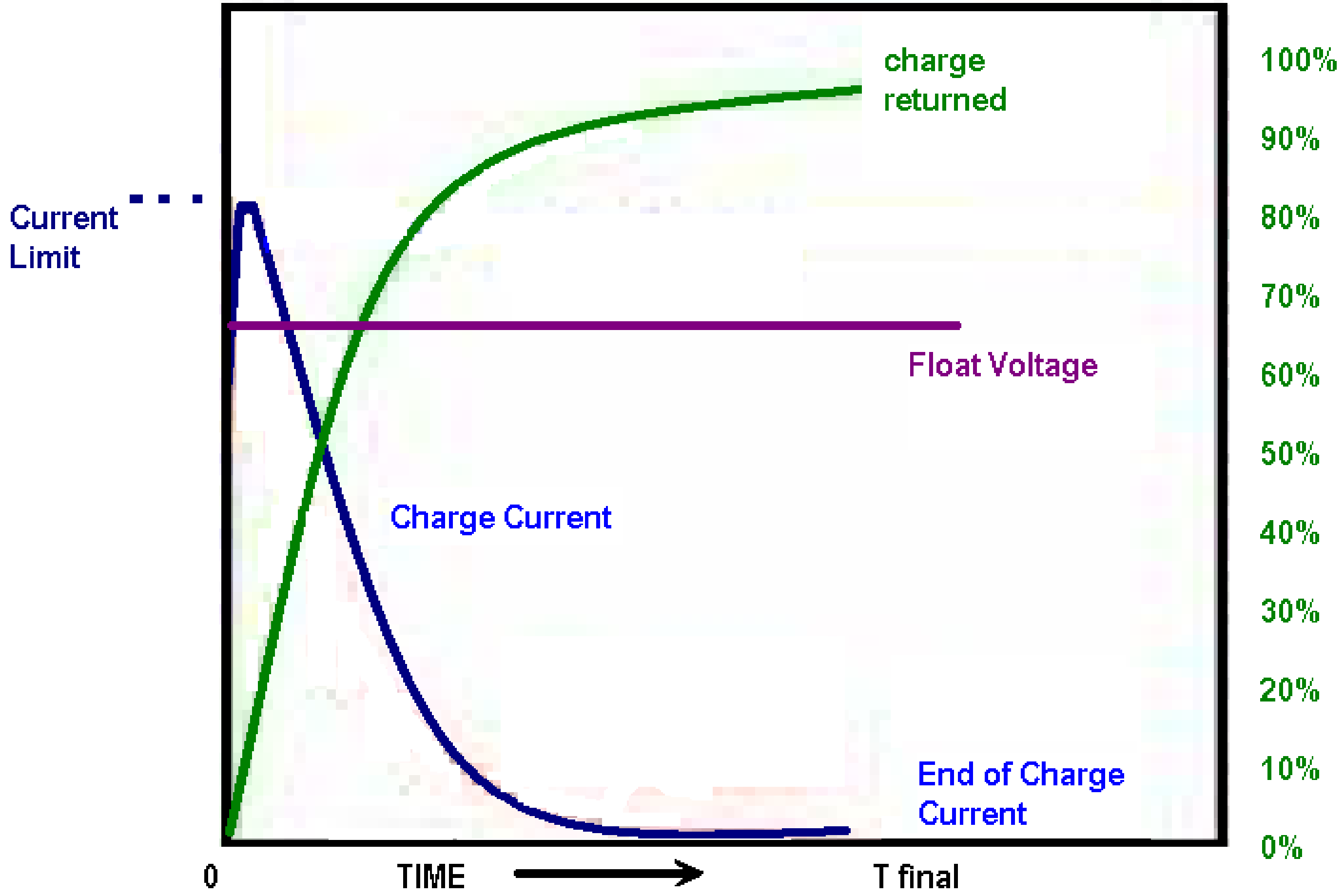
- **36" Clearance** requirement all around.
- **Fire Suppression** reqs keep changing.
- **Transport** must be by certified DOT driver.
- **Sizing programs** are not available to the public.
- **Higher purchase price.**

LITHIUM ION BATTERY – *SUMMARY*

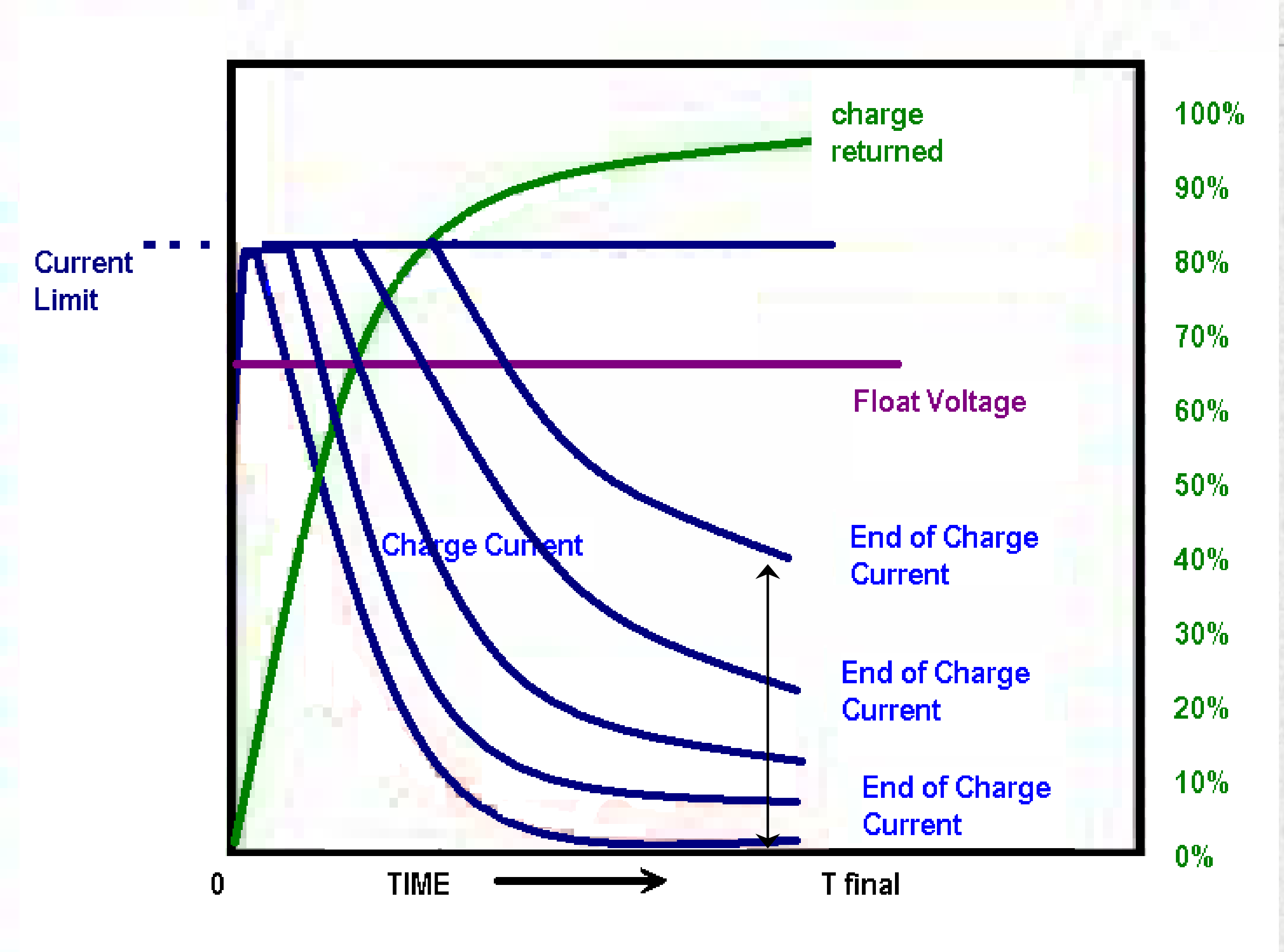
LIMITATIONS: *Continued*

- **Electronics required for battery management and monitoring are not as hardened for temperature extremes as the battery modules.**
- **System capacity and physical size is restricted by the NFPA 850**
- **Many manufacturers ship the batteries loose which means certified installation team has to be dispatched.**

Battery Recharge Curve

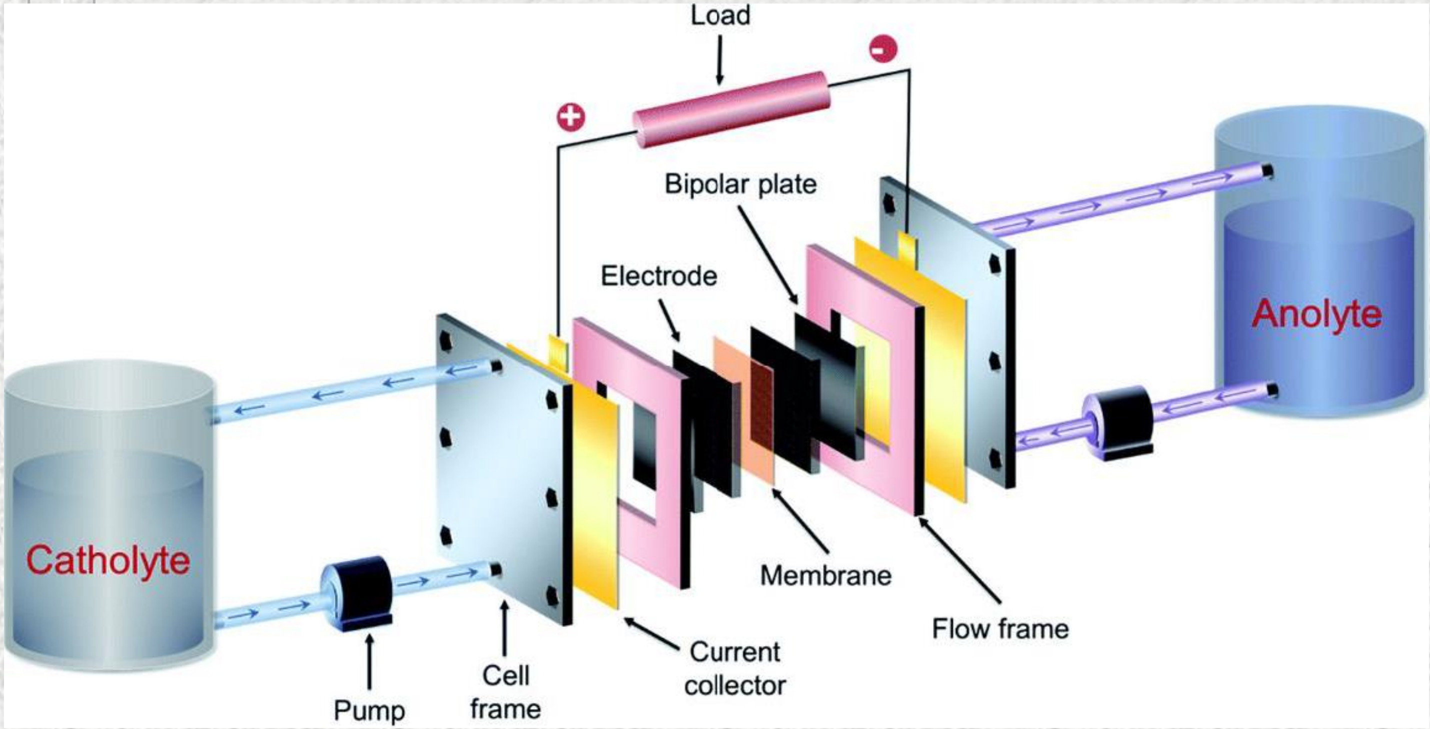


Classical Thermal Runaway



FLOW BATTERY – LARGE POWER

- **REDOX FLOW BATTERIES**



Ideal:
PV
Wind
Regen
Standby
Prime Power